

MEMORANDUM

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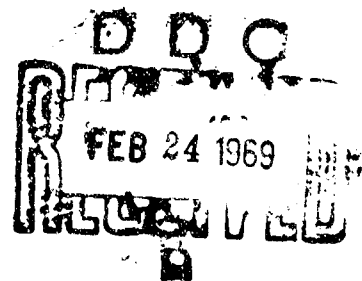
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THE RAND/TAC INFORMATION
AND ANALYSIS SYSTEM: VOLUME III—
THE ANALYSIS DESIGN AND METHODS

Fred Finnegan and Anders Sweetland

PREPARED FOR:

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The **RAND** *Corporation*
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PREFACE

The RAND/TAC information and analysis system provides for the collection, processing and analysis of operations, maintenance and supply data, using an IBM 1401 computer to assist in data purification and in the management and evaluation of aircraft operations and support at base level. The system is unique in that the data collected are identified with the specific sortie (and in some instances to the specific leg within the sortie). This allows the user to perform many kinds of analyses not ordinarily possible, relating mission use to reliability, manpower and spares usage.

The system grew out of a number of special field tests (e.g., Rapid Roger, Skoshi Tiger, Tack Down) exploring the feasibility of using a small business computer to assist with materiel and operations problems at base level. In the tests prior to Combat Dragon, it was necessary to "create" the maintenance analysts through an extensive educational process. Combat Dragon was unique in that Air Force personnel carried out the entire project from data collection through final writeup with no assistance from RAND, other than the initial training in the use of the system.

It is now possible to organize the loose collection of notes, procedures and programs into a formal system description. Accordingly, this RAND effort comprises four Memorandums containing essentially the package of materials used in training the Combat Dragon team. The information is organized as follows: Volume I (RM-5666-PR) is for data collectors and editors responsible for providing the data bank to be used in subsequent analyses; Volumes II (RM-5667-PR) and III (RM-5668-PR) are for analysts (especially people who will be doing maintenance analysis) to familiarize them with the available programs and analysis products, and to encourage them to ask questions and explore the data in an imaginative way; and Volume IV (RM-5669-PR) is for the "data services branch" of the evaluation or analysis team, to identify procedures and to impart an understanding of what the analyst is attempting to do.

Surprisingly, even though the system is entirely computerized, readers need not have a knowledge of computer hardware and software to

follow the text. A knowledge of the details of aircraft weapon systems would be useful, for although we describe such operations, the descriptions are somewhat cursory. In particular, a familiarity with aircraft maintenance procedures would be useful.

The concepts, techniques and programs of the RAND/TAC information and analysis system should be adaptable to future Air Force base-level management information systems, whether manual or highly mechanized. Provided that the appropriate computer is available, the RAND/TAC system can easily be introduced at a base and used without modification for field tests or other purposes. Recent changes in a number of standard Air Force forms and in data linkages, however, may make them preferable to the RAND/TAC forms for a particular base exercise.

With modest changes to current Air Force data collection procedures and reprogramming of the analysis packages, the system would provide a valuable supplement to current base analysis reports--a supplement more attuned to questions that are and should be asked by base maintenance management. The system will also provide a detailed guide and check list for the design-development of new base-level information systems and should provide direct input to analysis portions thereof.

SUMMARY

The RAND/TAC information and analysis system provides for the collection, processing and analysis of operations, maintenance and supply data, using a small business computer to assist in data purification and in the management and evaluation of aircraft operations and support at base level. It is unique in that operational and logistics variables are interrelated through several features of the data and analysis systems to permit identification of operational events connected with a particular sortie and relate these to explicit maintenance or supply actions preceding or following the sortie, management actions, and key environmental conditions.

The system consists of a series of forms for collecting operational data, maintenance actions, maintenance manpower availability, aerospace ground equipment utilization, supply demand, cannibalization and issue data, a series of computer programs and manual procedures for editing, reformatting and processing to provide basic displays, and other programs to provide basic analysis packages. The system is designed to minimize duplicative recording of data elements, and has flexible computer programs to permit a wide variety of analyses.

The four volumes constituting this effort present a complete system description, together with instructions on how to perform analyses using the system programs. Volume I (RM-5666-PR) contains the descriptions of and procedures for collecting and editing the data--the forms, procedures and program operating instructions. Volumes II (RM-5667-PR) and III (RM-5668-PR) are concerned with the analysis programs and procedures, and with analysis design and methods. The first emphasizes how the programs work, the second how questions can be answered. In a sense both volumes are written for a career that currently does not exist in the Air Force: the maintenance analog of the operations analyst. A person interested in this field should be versed not only in maintenance but also in data processing, computers, statistical methods and experimental design.

Each time RAND participated in a special field test, such as Combat Dragon, Skoshi Tiger, and Tack Down, it was necessary to "create" the maintenance analysts by an extensive educational process. Volume

II attempts to encapsulate the first part of that educational process. It introduces the prospective analysts to the data bank, the programs and the procedure needed to process the operations, maintenance and supply analysis data.

Volume III is based on the second stage of the learning process. It assumes that the user has now mastered the elements of the program and can focus his attention on answering questions. Thus it addresses analysis fundamentals: dependent and independent variables, data fields, sorting, data selection and tagging. Then it discusses a variety of areas of interest to maintenance management and shows how each can be explored with the system. Finally, some of the background and philosophy of experimental design is discussed.

Volume IV (RM-5669-PR) describes the computer programs used with the system. To encourage a rapprochement between the analysts and the programmers, we have attempted to include sufficient information for the programmer to understand the general outlines of what the analyst is attempting, as reflected by the functions of the computer programs.

ACKNOWLEDGMENTS

It is impossible to credit all those who made contributions to the system. Hall Logan (TAC-OA) and Sergeants James Fisher and Melvin Ericson (TAC) provided most of the maintenance procedures. Calvin Gogerty (RAND) designed the entire supply inclusions. Chauncey Bell (RAND) designed the "off-equipment" bench repair procedures. Sergeant Jack Marshall and Technical Sergeant Elias Martinez contributed to the 1401 programming, as did Mrs. Colleen Dodd of RAND. A special thanks is due Miss Doris Dong of RAND who did the art work.

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GLOSSARY

Abort rate	The rate of aborted sorties made by a unit in a given period. The most frequently used equation is the following: $\text{abort rate} = \frac{\text{sorties aborted}}{\text{sorties attempted}}$.
Action taken	The type of maintenance performed: repaired, removed and replaced, calibrated, etc.
AGE	Aerospace ground equipment.
AGE utilization	A display showing both active and standing flight-line utilization of AGE.
Aircraft display	Also called flight-line display and flight-line queue sort. Shows pictorially the maintenance and status history of each aircraft for a 24-hour period.
Base-line	Such data are counts of the times an event was attempted, e.g., sorties flown in a certain category.
Break-rates	Along with write-ups, break-rates are the major independent variables in determining aircraft recovery and turnaround, and are therefore the major determiners of sortie generation capability. Break-rates are determined for both aircraft and aircraft systems. The equation is as follows: $\text{break-rate} = \frac{\text{system fix count}}{\text{sorties flown}}$.
Chi-square	An analysis program that makes statistical comparisons of frequency counts to determine whether nonrandom behavior exists.
Code 799	No defect discovered.
Code 800	Removed or replaced to facilitate maintenance.
Code T	Removed for cannibalization.
Code U	Replaced after cannibalization.
Combat Dragon	An exercise with A-37A aircraft in Vietnam.
Cost-effectiveness	An exercise with F-4C aircraft at MacDill Air Force Base.
Daily package	Processing of operations, maintenance, supply and scheduling data by means of edit, error listing, and aircraft and work center displays.
Delay time	The accumulation of work interruptions on each system and each work center, by aircraft.
Demand rates	Most frequently, supply demand rates. Most frequently, $\text{demand rate} = \frac{\text{demand (requests)}}{\text{sorties flown}}$.

Deviation-Degradation (DEVDEG) program	A computer program. Lists and counts missions' deviation-degradation data from the 308 forms.
Dichotomous data	Data that has only two categories: for example, yes-no, 0-1, hit-miss, aborted-nonaborted, malfunctioned-nonmalfunctioned.
Easy data	Data collected by one person at a single collection point, as opposed to tough data.
Edit mask card	Locates the decimal phase that is edited into the data field just before printing.
Edit program	Searches for and identifies errors, reformats data, relieves data recorder of all possible unnecessary burden.
Eight/two pocket	Card drop pocket on the 1401.
Eighty-eighty (80-80) listing	Records are printed as they exist on the card (or tape) without separation of the fields.
Error listing	An image of each card containing a computer-detected error plus a description and location of each error.
ETTC	Estimated time to in-commission status.
ETR delay code	Equipment temporarily removed.
Field location card	Locates low- and high-order positions of the fields on the record.
Flight-line display	See aircraft display.
Frequency Counter (FREQ) program	Searches any field of unknown and unsorted data, builds a table, and counts the frequency of entries in the field.
Gang punch	To punch identical or constant information into all of a file of cards.
Gross fix time	Period from touchdown to end of maintenance. Includes unscheduled maintenance only.
Gross turnaround	Period from touchdown to end of maintenance, includes both scheduled and unscheduled maintenance.
Hard data	Keypunched data, as opposed to soft data.
Harmonic mean	The method of computing helps minimize the effect of unequal sample size by using the reciprocal of n.
Hourly Frequency Accumulate	A program that computes the frequency counts for resource utilization for each of the 24 hours during the day.
How malfunction code (how mal)	Describes the nature of the malfunction: burned, distorted, cracked, overheated, etc.

Independent variables	May affect system behavior, as opposed to dependent variables, which are the things being affected.
KBA	Killed by air.
K-97 report	Deck of maintenance data forwarded to the Logistics Command.
Lag time	Period from touchdown until maintenance begins.
Man-hours	Hours of direct labor.
Manpower Utilization Sequence	Relates personnel utilization (direct on-equipment labor) to sorties flown.
Manpower utilization	Searches each minute of the hour to find the number of men working each hour.
Manpower available	Produces a summary card showing the number of men available for each hour of each work center day.
Touchdown counts	Produces a card for each day showing the number of touchdowns for each hour of that day.
Mission essential items	Essential items for accomplishing the objective of the sortie.
MDC	Maintenance data collection portion of AFM 66-1.
MND	Maintenance nondeliveries.
Net fix time	Active fix time when work is being accomplished. Lags and delays are not included, refers only to unscheduled maintenance.
Net turnaround	Same as net fix time except it includes the scheduled maintenance as well.
NORM	Not operationally ready, maintenance.
NORS	Not operationally ready, supply.
NORS-G	Not operationally ready for supply, grounded.
N/P pocket	Card drop pocket on 1401.
NRTS	Not reparable this station.
Observed frequency	Count of successes, failures, aborts, etc.
Off-equipment file	MDC records of bench repair actions.
On-equipment bench repair	Repair done without item going through conventional materiel control channels.

OR rate	Operationally ready rate: OR rate = hours ready/hours possessed.
Oxnard format	The output format of the Edit program always includes clock hours. Oxnard refers to the project for which the format was designed.
Oxnard project	An exercise with F-101 aircraft at Oxnard Air Force Base.
Pearson product moment correlations	Statistical measure showing the amount of relationship between two measures.
PS code	Primary-secondary code. A column (in record format Ms) for use as a squadron (or other) designator.
Quantitative data	Manhours, elapsed time. Contrasts with frequency count data.
Rapid Roger	An exercise with F-4C aircraft in Thailand.
Recombine program	A special purpose program used in the Recovery Sequence. Eliminates duplications, adds a dummy sortie card to the end of each tail number subset and merges the sortie deck output by Single, First and Last with the nonsortie data output by Compute Elapsed Time.
Recovery Sequence	Preprocessed edit output data. This involves computing elapsed times, converting to Julian Calendar, and coding the sortie data for first, last and single sorties of the day. Requires Col. 80=0, =2, =3 records. Involves four programs: Compute Elapsed Time: Single, First, and Last; Recombine; and Clint.
Recovery Summary (RECSUM) program	An analysis program. Provides a complete, readily comprehensible summary of aircraft recovery and turnaround in a one-page general summary with back-up pages containing detail.
SAC Full Force	An exercise with B-52, B-47, KC-135 and KC-97 aircraft.
Sequential Frequency Distribution	Summarizes and displays events across 24-hour period.
7-cards	Produced by Clint program. Aircraft recovery records that include only the unscheduled maintenance action and the postflights. Aircraft turnaround records that include both scheduled and unscheduled maintenance data.
8-cards	Produced by Clint program. System records that include both scheduled and unscheduled maintenance actions.

9-cards	Produced by Clint program. Work center records that include the scheduled and unscheduled maintenance actions of all work centers.
Sick bird analysis	Determines whether individual tail numbers show atypical write-up rates based on the sorties flown, by obtaining the sortie and write-up counts for each aircraft card, using Chi-square testing for nonhomogeneity.
Single, First and Last (S/F/L) program	A special program used only in the Recovery Sequence. Makes a single sortie card from the pairs of sortie cards resulting when a flight crosses midnight. The program also determines and tags by tail number the sequence of sorties flown each day.
Skoshi Tiger	An exercise with F-4C, F-5A, and F-100 aircraft in Southeast Asia.
Soft data	Data not keypunched, as opposed to hard data. Generally verbal information.
Sortie length	Measured from takeoff to chock time (engine shut-down).
Sparrowhawk	An exercise with F-4C, F-5A, and A-4 aircraft at Eglin Air Force Base.
Splattergrams	Displays write-ups, sortie-by-sortie, to give a snapshot history of each aircraft. Program computes write-up rates for each aircraft and prints them at the end of each tail number.
Spread-field list	Provides a listing with each field isolated from the adjacent one by blanks. Much easier to read than an 80-80 listing.
Support general codes	Scheduled maintenance codes.
Supply 1050 system	The 1050 is the standard supply computer.
System repeat write-up analysis	A repeat write-up is identical to the write-up on the previous sortie.
Tack Down	An exercise with C-130 aircraft at Pope Air Force Base.
Throughput time	Time it takes to get a job out of the computer, measured from request to delivery.
Tough data	Data collected by many persons at many points, tough to get.
TMS	Type, model and series of aircraft.

Turnaround data	Output that includes all maintenance actions.
Units produced	A count of maintenance actions. Each job is assigned one unit of work.
Vector	A record that describes the status of a system at a given time.
When discovered code	Code showing when the malfunction is discovered: before flight, during flight, during inspection, etc.
Work Center Display	Also called work center queue sort. Shows 24-hour pictorial history of work center.
Work unit codes analysis	Summarizes on one page all the meaningful information on form 300 records for each work unit code.
Write-ups	A malfunction is "written-up," i.e., described. Along with break-rates, write-ups are the major independent variables in determining aircraft recovery and turnaround.
Z-score	Score expressed in sigma units.
ZI	Zone of Interior (USA)
Zone punch	11-punch (-) or 12-punch (+) on card used when punching Alpha or special characters.

I. INTRODUCTION

Most maintenance analyses involve two kinds of variables: independent variables, which may affect system behavior; and dependent variables, which may be affected by system behavior. Table 1 lists some variables that are often used in maintenance analysis.

Table 1

MAINTENANCE ANALYSIS VARIABLES

Dependent	Independent
Hung ordnance	Test periods
Aborts, air and ground	Squadrons--wings
Maintenance nondelivery	Weather conditions
Cancellations	Flying schedules
Late takeoffs	Theater conditions versus ZI
Write-up rates	Base dispersal
Break-rates	Centralized-decentralized
Demand rates, supply	Target difficulty
Demand rates, specialists	Flight profiles
Demand rates, AGE	Mission types
Aircraft turnaround, net and gross	Mission length
Recovery, net and gross	Experience length
Configuration times	Modification effects
Man-hours	Tail number differences
Sortie length	Time--age
Lags	Training effects
Delays	Procedure changes
Phased inspections	
Base self-sufficiency	
Cannibalization	
NORS-G	
Operationally ready rates	
Mission success	
Manpower utilization rates	
AGE utilization rates	

In the following pages, the examples show how to analyze the behavior of most of the dependent variables, but the list of independent variables is addressed mostly by implication. This is done because the list of dependent variables remains fairly constant, and these variables are the topics that maintenance management is most concerned about. The independent variables change, depending on the type of test or exercise and the use of the weapon system.

In using computers to assist in maintenance analysis, our basic data element is a record that originates as a keypunched card. The record always contains at least one dependent and one independent variable. The dependent variable is used in the calculations, and the independent variable is a computer control.

Thus the following sets of write-ups might occur:

Dependent Variable Write-up Count	Independent Variable Tail Number
5	7444
2	7444
1	7444
2	7448
4	7448
7	7448

The computer senses two fields in each card: the write-up, which it adds (accumulates), and the tail number. When it senses a change in the tail number field, most often it prints a summary, zeros out the accumulator, and begins processing the second tail number, and so on. To do this with a computer, the data must be sorted so that all like tail numbers are together.

This, in capsule form, is the essence of computerized analysis--sort, sense, and calculate. Unfortunately, this simplicity rarely occurs. Inspection of the various card formats shows that the typical record contains about 20 fields. As independent variables are identified, they are added to the records. To keep the data volume to manageable proportions, therefore, it is impossible to tolerate records containing only two entries.

There is a special form of multiple record format known as a vector, which is a record that describes the state of a system at a given time. A common vector is the daily summary analysis, which contains the following entries: the number of sorties scheduled (or fragged), the number flown, the counts of the various deviations, the MORS-G percentages, the number and kinds of targets struck, and so on. There are also entries for the independent variables: test periods, weather conditions, target difficulty, pilot experience, and ground-fire intensity, to name a few.

A vector of major interest to maintenance analysis describes the individual sorties and includes all pertinent maintenance information concerned with aircraft recovery from the sortie. The complete vector includes the operations information (where did it go, what did it do, what did it carry, what was its success); the maintenance information (what equipment was affected, what types of personnel were required to recover the aircraft; and the supply information (what kinds and how many parts were required). As with the previous vector, the associated independent variable codes are included to identify the circumstances that may be affecting the data.

A small number of independent variables can result in a large number of data categories because of the multiplication factor. For example, the analyst might collect data in two modes, centralized or dispersed, and each mode might be divided into day and night missions of three types--escort, strikes, and armed reconnaissance. This results in 12 unique categories (two modes x two clock times x three sortie types). The number of analyses that might be made from this can be horrendous. With the simplest of tests, one can check the effects of each of the three main variables (mode, clock-hour, and sortie type) and the effects of each of the 12 composite categories.

Assume the analyst has decided to sort the above sequence as follows: major on mode, intermediate on clock-hour, and minor on sortie type. The sorting sequence is always from lowest (minor) to highest (major); hence the minor pass would separate the data into three groups:

Minor = escort, strike and recce.

The intermediate pass would divide these three into two groups:

Day = strike, escort, recce
Night = strike, escort, recce.

The major sort further divides the data into two more groups:

Centralized = day = escort, strike, recce
Centralized = night = escort, strike, recce
Dispersed = day = escort, strike, recce
Dispersed = night = escort, strike, recce.

Assuming the sort was alphabetical, the various categories would appear in the following sequence in the deck if the codes were the first letter of the category.

1	CDE	Centralized, Day, Escort
2	CDR	Recce
3	CDS	Strike
4	CNE	Centralized, Night, Escort
5	CNR	Recce
6	CNS	Strike
7	DDE	Dispersed, Day, Escort
8	DDR	Recce
9	DDS	Strike
10	DNE	Dispersed, Night, Escort
11	DNR	Recce
12	DNS	Strike

If sorting and controlling were limited to this three-character field, the computer would output 12 summaries, one for each category, plus an additional summary for the entire sample.

This seemingly inordinate amount of discussion of sorting and controlling is intentional. Until the analyst can mentally sort and resort data, all the while visualizing how the computer output will look, he will only be able to analyze at the most pedestrian level. The best bet for the neophyte is to obtain a small deck (say 50 cards) and set up a major, a minor, and an 80-80 list for each pass on the card sorter. To do this he must understand the following sorting directions:

Sort	Major	Cols. 35-38	N	tail number
	Minor	Cols. 11-12	N	month

The N indicates a numeric sort. The sorting sequence is from lowest to highest order; hence the first sort is the lowest minor position, Col. 12. The sequence of the actual sort is

Major	Cols. 12, 11
Minor	Cols. 38, 37, 36, 35

Try this listing on each sorting pass, then reverse the major and minor, noting the effect on the sequencing. See Fig. 1.

The sorting-sensing-processing sequence that is the heart of an analysis is always preceded by a data selection-tagging sequence. It is necessary, however, to have some understanding of the what's and why's.

MINOR	MAJOR	MAJOR	MINOR
05	1620	05	1620
06	1620	05	1621
07	1620	05	1622
08	1620	05	1623
09	1620	05	1624
05	1621	05	1625
06	1621	05	1626
07	1621	05	1627
08	1621	05	1629
09	1621	06	1620
05	1622	06	1621
06	1622	06	1622
07	1622	06	1623
08	1622	06	1624
09	1622	06	1625
05	1623	06	1626
06	1623	06	1627
07	1623	06	1629
08	1623	07	1620
09	1623	07	1621
05	1624	07	1622
06	1624	07	1623
07	1624	07	1624
08	1624	07	1625
09	1624	07	1626
05	1625	07	1627
06	1625	07	1629
07	1625	08	1620
08	1625	08	1621
09	1625	08	1622
05	1626	08	1623
06	1626	08	1624
07	1626	08	1625
08	1626	08	1626
09	1626	08	1627
05	1627	08	1629
06	1627	09	1620
07	1627	09	1621
08	1627	09	1622
09	1627	09	1623
05	1629	09	1624
06	1629	09	1625
07	1629	09	1626
08	1629	09	1627
09	1629	09	1629

Fig. 1 -- Sorting illustration

(This shows effects of reversing the major and minor. Note that within each major entry, the minor appears in ascending order. Sorting can also be done in descending order if so desired.)

The selection process is necessitated by the multi-formatted data files. The first of these is the master file of all the Oxnard formats--approximately a dozen different record formats that all have (for sorting purposes) the tail numbers and start times in a common location. Most analyses require only one of these formats. For example, deviation analysis is done by selecting the data with an H in Col. 80. The instructions to the computer room are "Select data having an H in Col. 80". The computer operators decide the appropriate software and procedures. Often a multiple selection is required. "Select data having a zero in Col. 80 and 731 in Cols. 53-55". These are the combat damage records. The "and" is critical--it says that all records must meet both conditions: (a) they must have a zero in Col. 80, and (b) they must also have a 731 in Cols. 53-55. This instruction is entirely different from "Select data having a zero in Col. 80 or 731 in Cols. 53-55".*

Another way of selecting data is to use the matching record. A typical instance would be when we wish to select the particular subset of mission information that matches the sortie records (Col. 80=2). Both have the dates and the call signs on which the match is to be made. The instructions to the computer operators are "Select the mission records (Col. 80=2) that match the dates (Cols. 9-12) and call signs (Cols. 56-61) of the Col. 80=2 records".

The tagging (identification) is somewhat simpler: decide the codes and the columns. When possible use mnemonic codes, since this greatly facilitates the identification of the output: H for hard, E for easy, for example. See Fig. 2.

The more the analyst works with the data, the more he will be persuaded to avoid card storage. Rather, once the data are edited, he will keep them entirely on tape. One reason for this is that the tape record is not restricted to 80 columns. Our practice has been to restrict the basic record to 80 columns, but to use a standard 132-character tape record. The extra 52 characters are used for tagging, special sorting, and ancillary computations. Even this, at times, has been insufficient. Hence, most of the general purpose programs are written to accept a 264-character record.

*It would select any record meeting either or both conditions.

Group 1 22 3010140030101415 0773 20233 AM
0710000102100412 U 0779 20211 K3
0310209103102300 1 12142AC0779P683 0320000000 1002212142 20211 AKO
0410124104101305 1 12152AP0779P704 111C34106 1000412192 20211 AKO
0410000404100210 1 12142AD0779P590 0310000000 1002112142 20211 AKO
0710200107102100 2 12142AC0779P8036 0320000000 1002012142 20222 KRO
ME0CE091012250MO ECT -1 ENGINE 0779 20000 20222 KM
11101410 0779P 20222 KC
M14*01/213100426102CAA/AAA/LATE 1707790 DUE T CT CHC 20222 KB
1510070015101140 1 12142AB0779P797 13348 ANP 0006012142 20222 EK1
1710070017102400 P 0779 20233 K3
1810073118101130 2 12142AP0779P812 2320000800 1008013231 20233 AKO
1*10170119101730 1 12151AP0779P862 0341A00000 0000513330 20233 KRO
201022002310220020102305 100 0779 20233 K2
RB8888 123MOTR01

Group 2 300915503009155030091750 7500 20111 K2
2510204525102004525102215 100 7500 20233 K2
290914202909144529091700 100 7522 20111 A2
201006152010062020100955 100 7524 -0233 B2
231007402310074023100945 100 7524 20233 B2
1110152011101511101425 100 7532 20222 B2
191012551910134019101520 100 7532 20233 B2
CCCCC 202VAMP01
BB888 143FALC02
CCCCC 148MORNO1
AAAAA 178AVEN02
AAAAA 178WHIS04
CCCCC 178MAMP04
CCCCC 148FLAM02

Group 3 300915503009155030091750 7500 20111 K2
2510204525102004525102215 100 7500 20233 K2
290914202909144529091700 100 7522 20111 A2
201006152010062020100955 100 7524 M 20233 K2
231007402310074023100945 100 7524 M 20233 B2
1110152011101511101425 100 7532 M 20222 B2
191012551910134019101520 100 7532 E 20233 B2
CCCCC 202VAMP01
BB888 143FALC02
CCCCC 148MORNO1
AAAAA 178AVEN02
AAAAA 178WHIS04
CCCCC 178MAMP04
CCCCC 148FLAM02

Group 4 281021152010211528102245 0843 20233 A2
251014502510145525101440 100 7487 E 20233 B2
1010093010111025 7487 F 20311 J2
300915503009155030091750 7500 20111 K2
2510204525102004525102215 100 7500 20233 K2
290914202909144529091700 100 7522 20111 A2
14101255191014019101520 100 7532 20233 A2
290900042909000429090148 100 7538 20233 A2
311017553110142031101440 100 7544 F 20111 J2
1410030914100310141004 100 7552 F 20233 K2
230902502309025023090415 100 7553 F 20222 A2
250915502509155025091725 100 7553 F 20111 A2
0410003641000364100155 100 7553 20233 A2
04110400041104100410530 100 7538 20233 A2
041011050810112508101430 100 7496 M 20222 B2
201006152010062020100955 100 7524 M 20233 B2
231007402310074023100945 100 7524 M 20233 K2
1110152011101511101425 100 7532 M 20222 B2
191012551910134019101520 100 7532 M 20222 B2
RB888 123VAMP01
CCCCC 202M-LMO1
XXXXX FERTIER05
CCCCC 202VAMP01
BB888 143FALC02
CCCCC 148MORNO1
CCCCC 148FLAM02
BB888 201LEOP02
BB888 122ELM 02
AAAAA 183CHIS02
M8888 118ERM101
CCCCC 148LEOP01
BB888 177CAT002
CCCCC 167STILO2
CCCCC 178LIGM01
AAAAA 178AVEN02
AAAAA 178WHIS04
CCCCC 178MAMP04

Fig. 2 -- Mixed format file

(Group 1 is part of a file of mixed formats (Col. 80) containing several different types of records. Group 2 contains a subset of sortie records (Col. 80=2) selected from the original file. Group 3 shows the sorties tagged for hard and easy sortie type. Group 4 contains the sorted (Col. 70) data.)

II. METHODOLOGICAL EXAMPLES

AIRCRAFT TURNAROUND AND RECOVERY

The person familiar with statistical methodology realizes that the present AFM 66-1 system does not readily permit the computation of variances, the sine qua non of statistical manipulation. A number of attempts have been made to circumvent this shortcoming.

An early observation was that if data could be associated with the specific sortie, the variances of sortie dates could be obtained. Accordingly, a number of attempts were made to isolate data by sortie. The majority of these early attempts centered around the use of aircraft hours, which are entered on the AFTO-200 series documents.

These early explorations were facilitated by the particular data sample available (SAC B-52 data from Beale Air Force Base), which included the debriefing data and, fortunately, the aircraft hours as well. Although it was impossible to make a completely satisfactory by-sortie separation of the data (because aircraft hour entries were often inaccurately recorded), it was possible to demonstrate that interesting and meaningful analyses could be had if the data could be identified by sortie.* At that time the simple solution seemed to be to include a sortie number on all documents--an idea considerably easier to conceive than to implement. Hence the prospect of doing by-sortie retrieval was, at best, discouraging.

At this time, Bell and Smith were exploring the area of maintenance management and included, as a part of their exercises, the use of clock-hour entries on the AFTO-200 series document.** Consideration of these data leads to another method of isolating data by sortie. This technique used mixed record formats sorted by time-within-tail-number sequence. Treated in this manner, the data appear in a time-ordered sequence in which each sortie description record (Col. 80=2) is

* W. H. McGlothlin and T. S. Donaldson, Trends in Aircraft Maintenance Requirements, The RAND Corporation, RM-4049-PR, June 1964.

** C. F. Bell and T. C. Smith, The Oxnard Base Maintenance Management Improvement Program, The RAND Corporation, RM-3370-PR, November 1962.

followed by a series of maintenance records (Col. 80=0) which result from the aircraft recovery. Given this, it is possible to program a computer to summarize the data by sortie. On sensing the sortie description record, the computer "initializes" (clears all accumulators and records the contents of the sortie record). The computer then sweeps through the maintenance data, record by record, making the necessary calculations. On sensing the second sortie description record, the computer outputs the accumulations to this point, initializes, and starts accumulating the summaries of the second sortie, and so on.

Our sortie-summary program, known as Clint (Vol. II), produces three different records: a summary of the entire sortie; a summary of each two-digit system involved in the aircraft's recovery; and a summary of each work center that participates in the recovery. Each record is identified to the sortie by including three frequently used variables: the tail-number, the touchdown time, and the type of sortie code.

The time-sequence method of by-sortie retrieval has one shortcoming that shows up in certain analyses: Any deferred maintenance is associated with the sortie where the maintenance occurred, and not with the sortie on which the write-up appeared.* Consequently, those analyses concerned with determining the effects of sortie type are "contaminated" by including deferred items. As a general statement, this is not a serious problem for two reasons. First, the relationship of the deferrals to the sortie type tends to occur on a random basis, hence the random variance is generally increased (which can be circumvented by increasing the sample size). Second, the deferred items, by definition, are considerably less important than the mission essential items. An item must be noncritical or it cannot be deferred: for example, the deferrals are items such as hunged DZU fittings, frayed

*This deficiency may be avoided by collecting when-discovered clock times to permit the maintenance requirement to be identified with the sortie it was most nearly associated with. Of course, such associations do not prove relationships or cause and effect; but they represent useful approximations. It is interesting to note that collection of such information was included in the original Oxnard data system previously referenced.

cable lacings, missing bolt plates, and so on. Indeed, they are often referred to as "a bunch of junk."

Four sets of records that Clint produces have proved most useful. Our practice has been to keep them separated on each of four tapes.

1. The aircraft (7-cards) recovery records (format R1). These include only the unscheduled maintenance actions and the post flights.
2. The aircraft (7-cards) turnaround records (format R1). These include both scheduled and unscheduled maintenance data.
3. The system (8-cards) records (format R2) that are produced concurrently with the aircraft turnaround records. These include both the scheduled and unscheduled maintenance actions.
4. The work center (9-card) records (format R3) that are the analog of the system records. These include the actions of all of the work centers, scheduled and unscheduled maintenance.

The sortie data when output on tape (almost inevitably the case) is a record containing 264 characters. The sortie write-up count appears in Cols. 131-132, and the sortie break-rate data appear in Col. 130 (blank if no write-ups and 1 if one or more write-ups occur). The system breaks (coded blank or 1) recorded in Cols. 94 through 129 show the number of systems used.

Most analyses of the turnaround and recovery data will compare various periods or test phases. Providing that no statistical testing is desired, the quickest and most communicable way to obtain a complete data summary is to process the 7-card records with the Recovery Summary program (RECSUM, also called the Aircraft Histogram). If the unit is flying mostly daylight sorties, the most useful display will be obtained by majoring on the squadron designation (Col. 1) and minoring on single, first, and last sorties (Col. 21). The histogram entries most generally used are the Col. 21 entries (SFL), the first digit of the sortie type code (Col. 17), or the touchdown time code (Col. 16). Net fix time (Cols. 38-42) is generally used as the variable detailed in the matrix entries. See Fig. 3.

In most instances a statistical comparison is desired. This will generally be done using the Analysis of Variance program. Title (format C21) and a control card (format C2) must be made for each data field to be sensed. Since the sorting for RECSUM and Analysis of Variance is the same, our practice has been to obtain both sets of outputs while the data are so sorted. (The big element affecting throughput time is sorting, which generally takes five to ten times the amount of time that either of the two programs takes.)

In making up the title and control cards for Analysis of Variance, it is easier to layout and keypunch both if the common types of instruction are held separate. This is shown in the following.

TITLE CARD LAYOUT

Pass	Aircraft Turnaround by Test Period	Variable
1	↓	lags
2		delays
3		net fix
4		gross fix
5		units
6		man-hours
7		sortie length

CONTROL CARD LAYOUT

Sort		Control	Variable
Pass	Min 74-77	Min 74-77	
1	↓		28-32 lags
2			33-37 delays
3			38-42 net
4			37-47 gross
5			58-61 units
6			61-65 man-hours
7			66-68 sortie length

NOTE: Switches A, B, and D are "on" for all passes.

The arrows are keypunch instructions equivalent to ditto marks. The special instructions to the computer room always describe the specific

data bank (or type) to select. The third pass, net turnaround, is shown in Fig. 4.

As discussed in the Analysis of Variance section, the analyst may also wish to determine the impact of NORS-G on turnaround and recovery--and also, particularly when dealing with complex aircraft such as the F-4 and the B-52, to determine the effect of the phased inspections.

Gross turnaround and/or gross recovery figures are the most sensitive barometers to program changes; as the flying schedules increase, the turnaround times decrease and vice versa. These changes will show mostly in the delay portion of the turnaround. This is evidenced by the high, positive correlations between gross turnaround and delay entries. Pearson product moment correlations normally range from 0.90 to 0.95. In contrast, program changes have little impact on the net turnaround and/or net recovery data, although some reductions can be expected. By and large the mechanism for dealing with an increased flying program does not so much concern speeding up the turnaround, rather it insures that aircraft are not sitting idle. As would be expected, just as there is little change in the net turnaround data, there is also little change in the man-hour data when the program is altered. This is also shown by the correlations between net fix times and man-hours, which also tend to be high and positive--0.90 to 0.95.

Some sortie types are definitely harder on both aircraft and pilots, and all of the maintenance measures usually reflect this. The hard sorties result in more write-ups and hence require more fix actions. The high write-up rates result in increased man-hour consumption, increased units produced, increased turnaround times, and so on. In addition, the larger number of jobs increases the exposure to delay potential, hence aircraft delays also increase.

In contrast to the sortie type effect, the sortie length, per se, has little or no effect. In only one analysis (of several score) have we seen a sortie length effect, and this was minor. It occurred in a study comparing B-52 24-hour missions with B-52 8-hour missions; a 17-percent increase in man-hour consumption characterized the longer missions. Even in this instance, it could not be determined unequivocally that this was not a sortie type effect.

A fairly good estimate of how well a unit might do in an accelerated effort can be had by reviewing data on the first sorties of the day. These are the missions for which the aircraft has been turned around quickly because it is programmed to fly again the same day. These turnarounds consist mostly (but not entirely) of mission-essential maintenance actions.

One thing the analyst will quickly discover is another Parkinson's law: an aircraft takes as long to turn around as there is time available. This finding always engenders a feeling of dismay. On a moment's reflection, however, the analyst will recall that the turnaround data include all the launch actions (towing, top-up, final checkout, for example) that occur just before takeoff. Thus the turnaround data should be (and are) a fairly close representation of the flying schedule. This is why the net turnaround and delay data are important; they contain the germinal determinations of what could be done under stress.

When processing the aircraft recovery (as opposed to turnaround) data, one needs to remember that the recovery delay summaries consist of two elements: true delays resulting from no maintenance actions, and apparent delays resulting from the "holes" left by removing the scheduled maintenance data. The difference between the two shows the amount of scheduled maintenance that is not done concurrently with unscheduled maintenance. Where aircraft utilization must be increased, one does not like to see this difference appreciably exceed the combined time to fuel and upload the aircraft (neither action can be done concurrently with other maintenance), since this would indicate that there is not as much concurrent maintenance as might be desired.

WRITE-UPS AND BREAK-RATES

Of all the measures available to help understand and control aircraft maintenance, write-ups and break-rates are most important. These are the major independent variables in determining aircraft recovery and turnaround, and therefore the major determiners of sortie generation capability. Break-rates also determine the demand rates

for job specialists, AGE, and supply, and hence are of prime importance in solving resource allocation problems. As will be shown, the break-rates used in conjunction with the job duration data provide the bulk of information needed to comprehend sortie generation capability and resource needs. Since job durations tend to be stable, our major consideration is to understand the break-rate data.*

All unscheduled maintenance begins with a write-up in the 781A folder. Thus if the flight or the ground crews discover anything aberrant, they enter it (in English) in the 781 jacket. The 781A is organized in pairs of blocks. When a discrepancy is discovered, its characteristics are entered in a left-hand block; when the discrepancy is corrected (cleared), the correction is described in the corresponding right-hand block. The details of the correction are also entered in the associated AFTO 200 series forms--the form 300 of the RAND/TAC system. The 300 forms are then keypunched and serve as the basis of the write-up and break-rate computations.

In conjunction with the AFTO 200 series recording system, the Air Force Logistics Command publishes a manual (called the 06 manual) for each type, model and series (TMS) of aircraft. The -06 manuals describe the aircraft broken out into 5-digit work unit codes; for example, 111AB equals Radome zipper seal, and 511BE equals true air speed indicator. The first two digits are used in the write-up and break-rate computations. These two-digit break-outs represent the major aircraft systems: 11 airframe, 12 cockpit and fuselage, 13 landing gear, 14 flight controls, 23 propulsion system, and so on.

The Clint program does the bulk of the write-up computation using a table of 2-digit system codes to control processing. As each maintenance record is read in, the first two digits of the work unit code are compared with the system table. If a match is found, the summaries against that system are initiated. This continues until all data for that particular sortie are processed (indicated when the computer encounters the next sortie descriptor card). At this point, the

* T. S. Donaldson and A. F. Sweetland, Trends in F-101 Maintenance Requirements, The RAND Corporation, RM-4930-PR, April 1966.

computer produces a summary record for each 2-digit system that has required maintenance--one record for each system. (To reduce data volume, no record is produced for systems showing no maintenance.)

Given these system records (generally referred to as 8 cards because they have an 8 in Col. 2), the system break-rates are computed by dividing each system's record count by the number of sorties. The aircraft write-ups per sortie are obtained by dividing the total number of system records by the sortie count.

To facilitate this process, the Analysis of Variance program has been modified to perform all the necessary calculations. The instructions to the computer operator are "Select the Clint output 8-cards (format R2) having entries greater than zero in Col. 23 (zero entries in Col. 23 are the support general data), sort and control as follows":

Major	Col. 1	AN	squadron
Minor	Cols. 23-24	N	2-digit system
Variable	Cols. 38-42	N	net fix time

The appropriate sortie count is entered in Cols. 1-4 of the control card (format C2). The write-up rate appears at the bottom of the break-rate field. See Fig. 5.

Switch B--"off" to produce the system break-rates.

Switch G--"off" until all input data have been read in.
"on" allows the user to proceed from this point.

Aircraft break-rate is another measure obtainable from the data. This is defined as the number of sorties having at least one write-up, divided by the total number of sorties. Note that the scoring is dichotomous; the aircraft is "broken" (regardless of the number of write-ups) or "well." Clint produces this count. When the Clint program is output on tape, a complete record of system and aircraft write-ups is kept on the sortie (Col. 2-7) (format R1) tape record, which is 264 characters. Columns 94-129 are set aside to record system breaks; for example, if system 11 requires unscheduled maintenance, set Col. 94 equal to 1, otherwise set to blank. Just before output, the computer sweeps Cols. 94-129 counting the breaks. This count is entered in Cols. 131-132. If the write-up count is greater than zero, a 1 is entered in Col. 130 indicating a broken sortie. If

SAMPLE FREQUENCY DISTRIBUTION									
COMPUTED SYSTEM RELIABILITY - 0.95									
BASED ON 0.95									
PERCENTAGE COUNTS									
FIX-TIME	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Sample 1	100	10	10	10	10	10	10	10	10
Sample 2	100	10	10	10	10	10	10	10	10
Sample 3	100	10	10	10	10	10	10	10	10
Sample 4	100	10	10	10	10	10	10	10	10
Sample 5	100	10	10	10	10	10	10	10	10
Sample 6	100	10	10	10	10	10	10	10	10
Sample 7	100	10	10	10	10	10	10	10	10
Sample 8	100	10	10	10	10	10	10	10	10
Sample 9	100	10	10	10	10	10	10	10	10
Sample 10	100	10	10	10	10	10	10	10	10
Sample 11	100	10	10	10	10	10	10	10	10
Sample 12	100	10	10	10	10	10	10	10	10
Sample 13	100	10	10	10	10	10	10	10	10
Sample 14	100	10	10	10	10	10	10	10	10
Sample 15	100	10	10	10	10	10	10	10	10
Sample 16	100	10	10	10	10	10	10	10	10
Sample 17	100	10	10	10	10	10	10	10	10
Sample 18	100	10	10	10	10	10	10	10	10
Sample 19	100	10	10	10	10	10	10	10	10
Sample 20	100	10	10	10	10	10	10	10	10
Sample 21	100	10	10	10	10	10	10	10	10
Sample 22	100	10	10	10	10	10	10	10	10
Sample 23	100	10	10	10	10	10	10	10	10
Sample 24	100	10	10	10	10	10	10	10	10
Sample 25	100	10	10	10	10	10	10	10	10
Sample 26	100	10	10	10	10	10	10	10	10
Sample 27	100	10	10	10	10	10	10	10	10
Sample 28	100	10	10	10	10	10	10	10	10
Sample 29	100	10	10	10	10	10	10	10	10
Sample 30	100	10	10	10	10	10	10	10	10
Sample 31	100	10	10	10	10	10	10	10	10
Sample 32	100	10	10	10	10	10	10	10	10
Sample 33	100	10	10	10	10	10	10	10	10
Sample 34	100	10	10	10	10	10	10	10	10
Sample 35	100	10	10	10	10	10	10	10	10
Sample 36	100	10	10	10	10	10	10	10	10
Sample 37	100	10	10	10	10	10	10	10	10
Sample 38	100	10	10	10	10	10	10	10	10
Sample 39	100	10	10	10	10	10	10	10	10
Sample 40	100	10	10	10	10	10	10	10	10
Sample 41	100	10	10	10	10	10	10	10	10
Sample 42	100	10	10	10	10	10	10	10	10
Sample 43	100	10	10	10	10	10	10	10	10
Sample 44	100	10	10	10	10	10	10	10	10
Sample 45	100	10	10	10	10	10	10	10	10
Sample 46	100	10	10	10	10	10	10	10	10
Sample 47	100	10	10	10	10	10	10	10	10
Sample 48	100	10	10	10	10	10	10	10	10
Sample 49	100	10	10	10	10	10	10	10	10
Sample 50	100	10	10	10	10	10	10	10	10
Sample 51	100	10	10	10	10	10	10	10	10
Sample 52	100	10	10	10	10	10	10	10	10
Sample 53	100	10	10	10	10	10	10	10	10
Sample 54	100	10	10	10	10	10	10	10	10
Sample 55	100	10	10	10	10	10	10	10	10
Sample 56	100	10	10	10	10	10	10	10	10
Sample 57	100	10	10	10	10	10	10	10	10
Sample 58	100	10	10	10	10	10	10	10	10
Sample 59	100	10	10	10	10	10	10	10	10
Sample 60	100	10	10	10	10	10	10	10	10
Sample 61	100	10	10	10	10	10	10	10	10
Sample 62	100	10	10	10	10	10	10	10	10
Sample 63	100	10	10	10	10	10	10	10	10
Sample 64	100	10	10	10	10	10	10	10	10
Sample 65	100	10	10	10	10	10	10	10	10
Sample 66	100	10	10	10	10	10	10	10	10
Sample 67	100	10	10	10	10	10	10	10	10
Sample 68	100	10	10	10	10	10	10	10	10
Sample 69	100	10	10	10	10	10	10	10	10
Sample 70	100	10	10	10	10	10	10	10	10
Sample 71	100	10	10	10	10	10	10	10	10
Sample 72	100	10	10	10	10	10	10	10	10
Sample 73	100	10	10	10	10	10	10	10	10
Sample 74	100	10	10	10	10	10	10	10	10
Sample 75	100	10	10	10	10	10	10	10	10
Sample 76	100	10	10	10	10	10	10	10	10
Sample 77	100	10	10	10	10	10	10	10	10
Sample 78	100	10	10	10	10	10	10	10	10
Sample 79	100	10	10	10	10	10	10	10	10
Sample 80	100	10	10	10	10	10	10	10	10
Sample 81	100	10	10	10	10	10	10	10	10
Sample 82	100	10	10	10	10	10	10	10	10
Sample 83	100	10	10	10	10	10	10	10	10
Sample 84	100	10	10	10	10	10	10	10	10
Sample 85	100	10	10	10	10	10	10	10	10
Sample 86	100	10	10	10	10	10	10	10	10
Sample 87	100	10	10	10	10	10	10	10	10
Sample 88	100	10	10	10	10	10	10	10	10
Sample 89	100	10	10	10	10	10	10	10	10
Sample 90	100	10	10	10	10	10	10	10	10
Sample 91	100	10	10	10	10	10	10	10	10
Sample 92	100	10	10	10	10	10	10	10	10
Sample 93	100	10	10	10	10	10	10	10	10
Sample 94	100	10	10	10	10	10	10	10	10
Sample 95	100	10	10	10	10	10	10	10	10
Sample 96	100	10	10	10	10	10	10	10	10
Sample 97	100	10	10	10	10	10	10	10	10
Sample 98	100	10	10	10	10	10	10	10	10
Sample 99	100	10	10	10	10	10	10	10	10
Sample 100	100	10	10	10	10	10	10	10	10

Fig. 5 -- Aircraft break-rate analysis

(The last column on the right gives the system break-rates (reliability). The system fix-times (maintainability) are shown in the "means" column. The F-test is not appropriate for this sample and is ignored.)

no write-ups have occurred, the column is left blank. When these tape records are processed using the aircraft histogram program, RECSUM (Vol. II), the aircraft write-up and break-rate computations (totals and averages) appear automatically at the bottom of the page.

The aircraft write-ups and break-rates can also be obtained by using the Frequency Counter (FREQ) (Vol. II). In this instance, the appropriate system records (Cols. 2-8 and Col. 23 have only entries greater than zero) are selected. The data are sorted in Cols. 3-15, which allows all data for each sortie to be placed together. FREQ senses this same field. The total count is the number of write-ups; the line-counts are equal to the number of broken sorties. Dividing these two counts by the sortie count gives, respectively, the aircraft write-ups per sortie and the aircraft break-rates per sortie.

In general, write-up data are preferable to break-rate data. This is because the latter throw away much information by ignoring the number of write-ups. To show the relationships between write-ups and a number of the conventional maintenance measures, the following table is offered. The measures are based on aircraft recovery, not turn-around. Thus all support general actions except the postflights have been removed.

Table 2

PEARSON PRODUCT MOMENT CORRELATIONS BETWEEN AIRCRAFT
WRITE-UPS AND OTHER MAINTENANCE MEASURES

Measure	Aircraft		
	F-5A	F-100	F-4C
Net recovery	0.633	0.594	0.749
Gross recovery	0.507	0.431	0.580
Units	0.851	0.844	0.864
Man-hours	0.631	0.550	0.730

Not shown in these calculations are the aircraft delays, which correlate highly (about 0.95) with gross turnaround. The essence of the information in Table 2 is that a sortie with a large number of write-ups makes a difficult scheduling problem for job control.

Frequent write-up rates cause long turnarounds as well as increased demands for manpower and, presumably, other resources.

Of vital interest, of course, is what causes the frequency of write-ups. One factor is aircraft characteristics. Each TMS has its unique reliability characteristics. A complex aircraft such as the F-4C has write-up rates averaging 2.5 to 3.5 per sortie. In contrast, a simple aircraft such as the A-37A or the F-5A has low write-up rates averaging 0.5 to 0.8 per sortie. Given a specific TMS, the type of sortie has a definite impact on this basic break-rate. When one compares hard and easy missions flown by a specific wing or squadron, substantial differences show. As an example, the write-ups on the Rapid Roger F-4C hard sorties are 40 to 50 percent greater than those on the so-called easy sorties. Even greater differences have been observed in the ZI data: navigation training missions produce twice as many write-ups as guided air missile training missions do.

To summarize, then, since no other single variable affects maintenance behavior as much as the write-up, it is the measure that should receive the most attention.

JOB DURATIONS

When analyzing aircraft turnaround, one must remember that aircraft turnaround is a different phenomenon from the turnaround of the individual write-up. Aircraft turnaround time is almost entirely determined by the manner in which job control sequences a number of individual scheduled and unscheduled maintenance actions. It is the durations of these individual actions that we deal with in the following discussion.

There are two ways to compute job durations. From the viewpoint of maintenance, and particularly job control, the important consideration is the length of the individual actions; e.g., how long does it take to fix the radar system. The computed mean is often referred to as the job standard; e.g., the average fix time for the radar system is 1.8 hours.

There is another way of computing the average downtime. Instead of dividing the total downtime by the number of fixes, divide it by

the number of sorties. The means, which are much smaller than the job standards, provide an immediate comparison for determining the systems causing the most downtime. (The same comparison, of course, can be obtained from the total downtime data.) A similar comparison can be made by dividing the total system downtime by the total possessed aircraft hours. Multiplying this result by 100 yields the percentage of downtime caused by the system in question.

Both the job standards computations and the average-per-sortie computations are provided by the Analysis of Variance program. If switch B is set "on" and the sortie count is entered in Cols. 1-4 of the control card, the job standard computations appear under the "means" column and the average-per-sortie computations appear to the right of the variance computation. (If switch B is set "off", the break-rates appear in the break-rate computation field.) To obtain the above, select the 8-cards output by Clint (Col. 2=8).

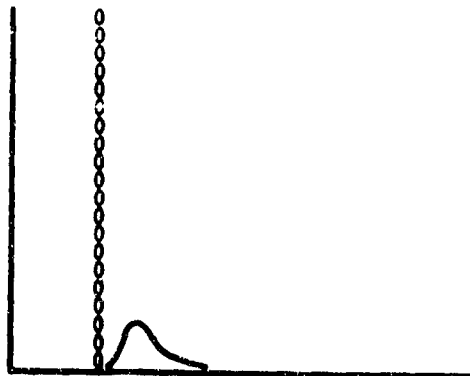
Sort, control	Major	Col.	1	squadron
	Minor	Cols.	23-24	system
	Variable	Cols.	38-42	net fix time

Switches A, B, D--"on".

Switch G--"off" until all the input data have been read in.

To proceed from this point, set G "on".

The F-test at the bottom of Fig. 6 applies only to the means columns (i.e., the job standards). An F-test is not produced for the average-per-sortie means. We have made no attempt to provide this latter because of the extremely peculiar distribution of the data--a tall column of zero fix times (for those sorties having no write-ups) followed by a tiny lognormal-like distribution:



SAMPLE FREQUENCY DISTRIBUTION									
2-15151 WORK UNIT CLIP SET 111 TEST VOUCHER 1404 727									
01-01 21-24 10-42									
FREQUENCY COUNTS									
2-- 51045	1-- 5.0	1-- 5.5	0 5.5	1 6.0	2 6.5	3 7.0	4 7.5	5 8.0	6 8.5
SAMPLE 1--	11	144	77	24	16	6	6	3	6
SAMPLE 2--	12	161	38	6	1	1	1	1	1
SAMPLE 3--	13	98	43	23	0	3	3	1	1
SAMPLE 4--	14	34	29	15	11	7	9	2	1
SAMPLE 5--	15	38	22	6	9	6	6	1	1
SAMPLE 6--	16	44	25	7	6	3	1	1	1
SAMPLE 7--	17	39	20	9	6	3	1	1	1
SAMPLE 8--	18	101	14	3	1	1	1	1	1
SAMPLE 9--	19	61	25	10	6	3	1	1	1
SAMPLE 10--	20	64	21	8	5	1	1	1	1
SAMPLE 11--	21	52	6	2	1	1	1	1	1
SAMPLE 12--	22	19	1	1	1	1	1	1	1
SAMPLE 13--	23	85	32	2	1	1	1	1	1
SAMPLE 14--	24	19	14	6	3	1	1	1	1
SAMPLE 15--	25	181	100	18	6	1	1	1	1
SAMPLE 16--	26	19	1	1	1	1	1	1	1
SAMPLE 17--	27	32	19	3	6	2	1	1	1
SAMPLE 18--	28	178	46	19	8	5	1	2	1
SAMPLE 19--	29	112	19	2	2	1	2	1	1
SAMPLE 20--	30	2	2	2	2	2	2	2	2
SAMPLE 21--	31	2	2	2	2	2	2	2	2
SAMPLE 22--	32	23	23	6	6	1	1	1	1
SAMPLE 23--	33	6	6	6	1	1	1	1	1
SAMPLE 24--	34	6	6	6	1	1	1	1	1
SAMPLE 25--	35	2	2	2	2	2	2	2	2
SAMPLE TOTALS									
CUMULATIVE PERCENT									
OUT OF 1000000									
1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
OUT OF 1000000									
1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
OUT OF 1000000									
1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
OUT OF 1000000									
1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
OUT OF 1000000									
1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
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1528 406 171 87 45 43 24 10 14 4 12 3 3									
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OUT OF 1000000									
1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
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1528 406 171 87 45 43 24 10 14 4 12 3 3									
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1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
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1528 406 171 87 45 43 24 10 14 4 12 3 3									
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50 41 40 91 74 96 97 97 94 96 99 99 99									
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1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
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1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
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1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
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1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
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1528 406 171 87 45 43 24 10 14 4 12 3 3									
50 41 40 91 74 96 97 97 94 96 99 99 99									
OUT OF 1000000									
1528 40									

In instances where we have tested the average-per-sortie means, which was accomplished by adding the appropriate number of zero fix-times records ($n = \text{sortie count} - \text{write-up counts}$), the data have pronounced inequality of variance (see Sec. III).

Our experience has been that the job standards computed on net fix times remain remarkably stable despite dramatic changes in the demands levied on the system. For example, in a recent exercise in Southeast Asia, although the sortie production rate was doubled, almost all the system net fix times (unscheduled maintenance) remained unchanged. The causes of the exceptions to this were immediately determinable. For example, an influx of new pilots was associated with an immediate increase in the number of write-ups on the fire control system (reflecting the uneasiness of the new pilots in a combat setting). The job standards showed a distinct decrease in length, with a high proportion of how mal 799 (no defect discovered) and minor alignments. In two to three weeks, when the pilots became adjusted to the combat setting, the write-up rates returned to normal levels as did the fix times. As a general statement, changes in net fix times almost always indicate atypical or abnormal conditions and should be immediately investigated.

When computing the job standards, it is also desirable to determine the amount of job delays. These delays are caused by interruptions to the job in progress; for example, the item is removed for bench check or the job is deferred because of more pressing demands. Shift changes and lunch breaks also contribute heavily to delays. The data, which are already sorted, are run through Analysis of Variance using Cols. 33-37 (delays) as a variable and again using Cols. 43-47 (gross fix times) as a second variable. As indicated by the following data, the system delay times can be substantive. Note the reduction in system delays in test periods 2 and 7. This is almost entirely due to management action.

Table 3

TWO-DIGIT SYSTEM DELAY AVERAGE IN HOURS
(Unscheduled maintenance only)

Test Period	Mean	Totals	Sorties Flown
1	22.02	36025.1	454
2	5.89	11941.0	563
3	14.27	8689.9	139
4	13.10	43637.9	844
5	15.96	31461.1	503
6	15.05	73029.8	1308
7	4.78	12769.1	870

It is worth noting that the amount of system delays that Clint computes is much greater (more than 20 times) than those reported as aircraft delays. For this reason we caution the analyst against frequently using the delay codes in an absolute sense. Adequate delay reporting is often difficult to obtain; nonetheless it does provide useful information.

WORK CENTER DEMAND RATES AND JOB DURATIONS

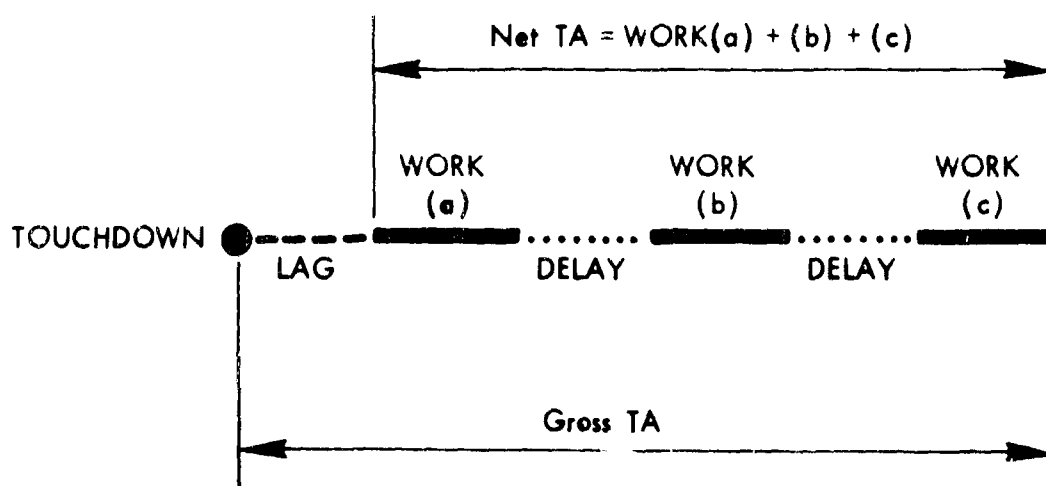
As a general statement, the work center data are not of as much interest to the operational unit. This occurs partly because a more complete set of work center analyses has been developed for use at the unit level (see the section on Finding the Short Resource), and partly because the system break-rate and job duration analysis provides much of the information made available by the work center analysis. This occurs because most work center actions are defined by the work unit codes; the engine shop works on the power plants, the radar shop on the radars, and so on.

The processing of the work center data is identical to that of the break-rate and job durations except that the 9-cards of the Clint output (Col. 2-9, format R3) are used, and the minor sense is Cols. 23-27 (instead of 23-24).

Sort, control	Major	Col. 1	squadron
	Minor	Cols. 23-27	work center
	Variable	Cols. 38-42	net fix

It is recommended that the delays (Cols. 33-37) and gross fix times (Cols. 43-47) also be computed at this time. As with the 8-card data, lag times are not included in the gross fix times.

When doing the manpower analysis, to aid in determining shift allocations, it is helpful to compute the work center lag times (lags are measured from touchdown to the beginning of the first job). On doing this, the analyst often finds that some work centers rarely, if ever, start work until two to three hours after touchdown. In these instances, the appropriate reporting times can often be adjusted to avoid the problems that arise when a work center has nothing to do at the beginning of a shift, but must work overtime at the end.



A data processing problem occasionally arises because of the local practice of redefining work centers. For example, a unit establishes a special work center to do pre- and postflights exclusively. After trying this for a while, it goes back to the regular crew-chief type of operation. The result is that the work center demand rates

and manpower utilization data seem to show sudden increases and decreases. This makes the manpower distributions awkward to adjust. Where the work center numbering is changed in the middle of the job, the fix is seen by Clint as being two separate jobs. The solution is to recode the data giving a common work center code to the segmented work centers. This should be done with the data used for Clint input, not the 9 cards of the Clint output.

As previously mentioned, the work center analysis should not be expected to provide much information beyond that obtained from the 2-digit system analysis (i.e., the instrument shop works on instruments). The exceptions to this are the crew chiefs who do a variety of repair actions in addition to the servicing and inspections. Note also that most shops will record a variety of support general actions (e.g., crystal changes) as well as a number of special inspections. In general, this is a small part of the workload.

The analyst should remember that the 9-card analysis only includes flight-line actions. Bench actions are excluded. Hence the 9-card data do not tell the complete story. Some shops (particularly the avionics and engine shops) expend more than 50 percent of their manpower on shop actions. The off-equipment utilization is obtained from the normal AFM 66-1 data bank following AFM 171-14 procedures.

DIFFERENT BREAK AND RECOVERY COMPUTATIONS

While the most useful computations are those of the turnaround characteristics, because they give the best picture of weapon system capability, they are not the only useful computations. Indeed, when our interest is concerned more with hardware characteristics, there are a number of better ways to process the data. This is shown in the following.

Suppose the analyst is interested in hardware reliability-maintainability. Then he would probably not wish to have the data "contaminated" with the tech order compliance information indicated by the following no defect, how malfunctioned codes:

- 797 Technical order previously complied with
- 798 Equipment to be replaced, modified or removed
- 801 Technical order compliance
- 802 Technical order partial compliance
- 803 Time change
- 804 Removed for scheduled maintenance
- 811 Class modification

Depending on the particular question, all or part of these data might better be excluded from the computations. The analyst might wish to exclude two other no defect, how malfunctioned codes that are not related to technical orders. These are code 800 (removed or replaced to facilitate maintenance) and code 799 (no defect discovered). Code 799 is used when the specialist's diagnosis does not confirm the write-up or when he is installing a good part.

While pursuing the hardware characteristics area, our analyst may also wish to think about action taken codes T (removed for cannibalization) and U (replaced after cannibalization). These are both actions on the aircraft being cannibalized, and are concerned with obtaining and replacing a good unit for repairing a broken aircraft.

In looking at hardware characteristics, there are times when one also wishes to look at actions in more detail than at the 2-digit system level (i.e., the hot section of the power plant, uploading and configuring actions, preflights, postflights, and so on). In these instances, the data must first be recoded. We suggest using 2-digit alpha mnemonics to insure that the data do not become confused with the regular data pool. The new codes must be included in the table of system codes Clint uses.

PHASED AND HOURLY INSPECTIONS

The phase sortie includes three types of data: the regular data resulting from the effects of the sortie, the inspection data resulting when the inspection crew works through the inspection cards, and the fix data detailing the repair of those items found defective during the inspections. The details of the phase sortie are best seen by reviewing one of the flight-line displays. Following touchdown, the maintenance actions on the display first show the conventional

entries of normal recovery. The start of the phase inspections is signaled by a P (or E for hourly inspections) appearing in the T (for type of maintenance) column. This is taken from the second character of the work order prefix. The phase inspection records can also be identified by the work unit code which is always 0341, followed by an alpha identifying the particular phase deck (or book) being used, e.g., A for book 1, B for book 2, and so forth.

The fix actions that result from the inspection are identified in the when discovered code (Col. 92) by an M which stands for discovered during special inspection. Of the many analyses that could be done on these data, the following is presented as the best first pass. Make a distribution(s) of the turnaround of the phased sortie and compare it with the distribution(s) of only the phase items. This is detailed in the following.

Select the Clint output sortie cards from the all systems data (Col. 2=7) having a P in Col. 20. (It is best to 80-80 list these cards at this point to find any data errors by cross-checking the 80-80 listing with the flight-line displays.) Using Analysis of Variance, obtain the net and gross turnaround distributions and also the man-hour distributions. In the following example, the controls major on the squadron and minor on the month. The three title cards, of course, identify the analysis and type of data.

Pass	Major & Minor	Sort	Control	Variable	Switches "On"
1	Maj 1-1 Min 8-9	Squadron Month	1-1 8-9	38-42 net	A, B, D
2	Maj 1-1 Min 8-9	Squadron Month	1-1 8-9	43-47 gross	A, B, D
3	Maj 1-1 Min 8-9	Squadron Month	1-1 8-9	61-65 man-hours	A, B, D

The comparable set of distributions using only the phase data involves a special Clint run. Select only those form 300 records (zero in Col. 80) having a P in Col. 34 (inspection data) or an M in Col. 52 (fix data). These are combined with the sortie cards (Col. 80=2). It is easier and simpler to select all the sortie cards and set the

Analysis of Variance program to output only non-zero data rather than to isolate the phase sorties. This special set of data is then processed with Analysis of Variance using the same sortings and control. The resulting distributions show only the inspection and fix actions of the phased inspections. Partial results of such a study are shown in Table 4.

Table 4
PHASED INSPECTION ANALYSIS
(Time in Hours)

Test Period	Total Turnaround	Phase Turnaround	Difference	Number
1	37.09	31.40	5.69	11
2	39.94	30.07	9.87	14
3	62.81	24.66	38.15	5
4	106.50	47.24	59.26	8
5	109.90	37.02	72.88	9
6	80.30	37.46	42.93	50
7	60.66	48.17	12.49	31

Note the large differences in test periods 3-6. They suggest that aircraft are being "lost" somewhere between the flight-line and the phase docks.

It is often desirable to know how much of the inspection man-hours consumption is due to the inspection and how much to the fix. If it is necessary to test statistically whether these have been increasing or decreasing on a month-by-month basis, there is no alternative but to run each separately through Clint. The first run uses the sortie cards (Col. 80-2) and the P in Col. 34 cards. This gives the inspection data. The second run uses the sortie cards and the M in Col. 52. Each Clint output having a P in Col. 20 of the sortie summary cards is sorted by month within squadron and processed with Analysis of Variance sensing the man-hour field (Cols. 61-65) as the variable. In this instance, since the object is to determine whether the distribution of means is homogeneous, the F-test is inspected.

As a general statement, the small amount of data does not encourage much investigation of the phase inspections in great detail.

But occasionally one wishes to know which systems are showing what sort of fix actions. This is easily done by processing the M in Col. 52 in the following manner. Using FREQ, determine the counts of the 5-digit work unit codes (Cols. 46-50 of the 80=0 records). Select those with sufficient frequency to warrant further investigation with the Compute Elapsed Time program, then process using Analysis of Variance. Major on the work unit code (Cols. 46-50), minor on the how mal code (Cols. 53-55). Sense Cols. 70-72 (elapsed time) for the variable. This output will give the how mal counts for each code, plus the associated fix times for each work unit code. The work unit code totals are shown at the bottom. If the data sample is small, an 80-80 listing is frequently sufficient for most purposes. In this instance sort, as above, majoring on work unit code and minoring on how mal codes.

DEVIATIONS AND DEGRADATIONS

Frankly, doing deviation analysis on ZI training sorties is something less than exciting. After you discover for the 20th time that ground aborts are resulting from faulty nose wheel steering, dragging brakes and sheared starter shafts, the thrill is gone. With combat data it is an entirely different story, since each deviation or degradation is critical. Each represents a missed or degraded mission; each represents a failure of the weapon system in a situation where failure is intolerable. This is the one time that the game is played for keeps. Hence each item is critical. For that reason we wish to review each in detail.

The deviation-degradation (DEVDEG) data have an H in Col. 80 (format U). The best first approach is to use the Compute Elapsed Time program and punch out these data, sort by deviation code (Cols. 7-8), and process using DEVDEG. This output is reviewed for coding errors which must first be corrected. The correction is easy because the verbal explanations, listed by the program, give the story of what happened. Following corrections, the data are sorted: Major on code (Cols. 7-8), intermediate on system (46-50), and minor on month (Cols. 11-12) and day (Cols. 9-10). The data are again processed with DEVDEG.

The mission degradation data appear at the top of the output because the degradations use a blank in the deviation code field. The deviation data follow in alphabetical order.

The intermediate sort separates the data by work unit code. This makes it easy to group them by the appropriate indenture level. The verbal data give a complete picture of what happened. When knowledgeable maintenance people inspect the verbal entries, they can quickly isolate failures due to hardware deficiency and those most likely due to human errors (both pilots and maintenance personnel). The human errors are of particular interest because something can be done immediately to alleviate the problem.

Since DEVDEG data are frequency counts, Chi-square is the appropriate statistical test. Either Analysis of Variance or FREQ will produce the input data in appropriate form. Combat data are inevitably tagged by phase or test period.

If Analysis of Variance is used to obtain the Chi-square input, the base-line data can be included in the punched output. This is entered in Cols. 1-4 of the Analysis of Variance control card. Setting switch D "off" produces the Chi-square input deck (format X). The base-line data must be added by keypunching if FREQ has been used to obtain the Chi-square input.

As an aside, one can get into some interesting, but pointless discussions about the best base-line to use. The preferred one is sorties attempted. This is generally computed by subtracting sorties cancelled from sorties scheduled (fragged) counts. Sorties attempted is the most meaningful maintenance condition available. Sorties attempted and sorties scheduled are generally more readily available than sorties attempted and cancelled counts.

The Chi-square deck output by Analysis of Variance will be in minor within major sequence, i.e., deviation code within time period. To be useful, the data must be resorted by reversing major and minor. In other words, sort as minor (Cols. 13-14), which puts each type of deviation together. Within each are the records for the periods, ordered in proper sequence.

The Chi-square input deck can also be obtained by using FREQ. This also provides the major and minor entries. As indicated, the data must have the base-line added (Cols. 1-6 right adjusted). To do this, sort on major (i.e., period) and, for each major, there must be a gang punch in the proper base-line. The deck is then sorted on the minor, which orders data by period within deviation code.

To process the decks above with Chi-square, make one title card (format C15) and one control card (format C16), set the appropriate switches, load and go. See Fig. 7.

In analyzing deviation data, particularly abort data, it is advisable to check the magnitude of the deviations as well as the trend. Each FMS has a hardware base-line that is the inherent characteristic. Onto this is superimposed a human error factor. This reflects the adequacy of the training, procedures, and supervision. The object is to keep the rates at the hardware base-line. As mentioned, the verbal information provides an excellent means of isolating the human error factors from the other types. The maintenance nondeliveries (MNDs) are a function of scheduling: poor scheduling (too clustered, too tightly spaced) results in high MND rates. MNDs tend to show especially when sortie rates are high. Review the data to determine when the MNDs occurred and check the associated schedule patterns. To do this, select the sortie cards (Col. 80=2, format M) for the periods in question, gang punch a common tail number (i.e., tail number 8888) into all records, and process with the Flightline Display program. This will show the scheduled and flown pattern for each day involved. To be more elegant, add the Col. 80=H (deviation comments, format U). This gives the complete picture of the scheduling MND history.

BATTLE DAMAGE ANALYSIS

The analyst will not have much battle damage data to work with since the probability of battle damage is, fortunately, quite low. When such damage is incurred, there are three separate kinds of records that must be reviewed:

1. Aircraft losses--the details of this are picked up from operations debrief.

GROUND ABORTS FOR SEVEN PHASES OF THE TEST													
BASE-LINE	FO	FT	D2/FT	MEANS	-3	-2	-1	0	1	2	3	4	5
527	29	20.80	3.36	.055	.	.	.	.	111	.	.	.	.
666	34	26.29	2.36	.051	.	.	.	.	112	.	.	.	.
240	6	9.47	1.33	.025	.	.	113	.	.	.	.	.	.
907	48	35.80	5.33*	.053	.	.	.	.	211	.	.	.	.
518	10	20.45	5.56*	.019***	.	321	.	.	.	.	.	.	.
1513	64	60.51	.21	.042	.	.	.	322	.	.	.	.	.
980	21	38.68	8.41**	.021***	.	323	.	.	.	.	.	.	.
TOTAL	5371	212											
WEIGHTED GRAND MEAN--				.039									
CHI-SQUARE--				25.55									
DF--				6									

2. Heavy damage--the aircraft is turned over to the RAM (Rapid Area Maintenance) team. Here the loss is a matter of days and even weeks. This time needs to be recorded. The details of the damage can be picked up from the quality control records.
3. Light damage--the aircraft remains on the possessed aircraft list and the squadron repairs the damage. This repair can be identified and, hence, be used as the beginning point of the analysis.

The first step is to isolate the sorties and recoveries on which the damage occurred. This is done with the instruction "Select data (format K) having a zero in Col. 80 and 731 in Cols. 53-55, sort by time within tail number, and list 80-80". 731 is the how malfunctioned code for battle damage. See Fig. 8.

The 80-80 list is scanned for clusters of dates (generally one to four days) that indicate the on-going repair. In scanning the list, note the action taken codes that appear in Col. 51. Many of the codes will be P for removal. Note that the associated Q actions are not shown. Hence the analyst sees only half of the maintenance involved. The reason is that only the removal is coded 731, battle damage. The proper how mal code for installing the good part is 799, no defect. We select only how mal code 731.

The easiest way to get the whole story is to use the data clusters from the 80-80 listing to isolate the sortie involving the damage. Select the master file data beginning a day or so earlier than the start of the cluster and ending a day or so later. This insures getting a complete turnaround bounded by a sortie card at each end. Make a flight-line display of these data and check to see that the complete turnaround is available. Circle the how mal codes 731 in red and identify the associated sortie.

The analysis can often be made directly from the display. Or, in more elegant fashion, the Col. 2-7 and 9 cards from the Clint output can be selected for a more rigid analysis. The following must be determined:

Total aircraft hours lost
Total man-hours consumed
Average fix time, all systems

		HOW	ANMAL	JD ET
2612160126122200	2	12141AB7589FPM700	14530PF731	001201214136006032212JJ0360
1511000215110530	3	12044AB7629FPM095	23200PF731	10164132313190553211MA0319
2501173125132000	5	12141AB7641FPP106	23200PF731	001251323139002532331KJ0390
2501213125132230	5	12141AB7641FPP106	23200PF731	100501323139001032331MJ0390
2708170127081930	1	12041AB7643FP	1123CGD731	10025131302390251121IGA0239
0812003108120200	3	12044AB7644FPL024	23200PF731	100441323134201532212EA0342
0812022108120400	3	12044AB7644FPM914	23200PF731	100491323134201732212HA0342
0812171108121730	1	12044AB7644FPM010	111LEPF731	100031331034200332212QA0342
1012122110121415	4	13310AB7644FPP877	4616FXD731	100761332034401932212HA0344
1012173110121800	1	13310AB7644FPM010	111HPPF731	100051331034400532212AA0344
1012184110121900	1	13310AB7644FPM010	111KLPPF731	100031331034400332212CA0344
1012190110121920	1	13310AB7644FPM010	111KEPF731	100031331034400332212DA0344
1012192110121935	1	13310AB7644FPM010	111KFPF731	100021331034400232212EA0344
1012200110122020	1	13310AB7644FPM010	111KHPPF731	100031331034400332212GA0344
2909053129091130	1	12142AB7644FPM119	14530GF731	100601313027206020111PK0272
10101.3110101145	4	12041AB7650FPM173	111AAGF731	100101204128300220222MA0283
2209220122092300	4	12041AB7650FPM032	111AARF731	100401204126501020111BA0265
0201210102132200	2	12041AB7652FPP649	111GQGF731	100201313036701032221KA0367
0201220302132305	2	12041AB7652FPP649	111FJGF731	100211313036701032221LA0367
0201230702132400	2	12041AB7652FPP649	111DUGF731	100181313036700932221MA0367
2109011621090630	1	12041AB7673FPM217	14310PF731	000521204126405211311NA0264
2109160121092400	5	12041AB7673FPS442	14310QF731	004001331226408011311KA0264
2209000222090010	5	12041AB7673FP	14310QF731	000071331226500120111AA0265
2209073122090930	4	12041AB7673FPS090	23200PF731	100801323126502020111CA0265
2209170122091800	3	12041AB7673FPP505	111HCRF731	100301204126501020111GA0265
2308164623082145	5	12041AB7673FP	23000PF731	102501323123505011122HA0235
2408094124081000	1	12041AB7673FP	111GUPF731	100031204123600311211FA0236
2408180624081930	2	12041AB7673FP	11339RM731	100281204123601411211MA0236
2508091625081015	1	12041AB7673FP	111HARF731	100101204123701011211MA0237
2508101625081200	1	12041AB7673FP	14549RF731	100171204123701711211MA0237
2601170126131900	5	12043AB7673FPM940	23200PF731	101001323139102032332FA0391
0909190109092000	2	12141AB7680FP	1471CGD731	100201334025201011233EJ0252
1110200111102400	5	12141AB7680FPS237	23000PC731	002001214128404020222LJ0284
1210000212100130	4	12141AB7680FPM095	23200PF731	1005913231285015202228J0285
1210013612100200	2	12141AB7680FPM096	111HCRF731	000081214128500420222CJ0285
1210142612101555	3	12141AB7680FPM089	1431DRF731	000451331128501520222JJ0285
1210160112102400	5	12141AB7680FPM086	1431DRF731	004001331228508020222KJ0285
1210163112101830	1	12141AB7680FPM069	111KHPPF731	100201214128502020222MJ0285
1310000213100805	4	12141AB7680FPM981	1431DRF731	003221331328608120222AJ0286
1310080113100930	1	12141AB7680FPM119	111FJGR731	100151313028601520222EJ0286
1310080113101700	2	12141AB7680FPM119	111TJGR731	101801313028609020222HJ0286
1310080613101600	4	12141AB7680FPM581	1431DRF731	1031613311286079202228J0286
1310083113101000	1	12141AB7680FPM119	111FJGR731	100151313028601520222FJ0286
1310100113101200	1	12141AB7680FPM119	111FJGR731	100201313028602020222GJ0286
2001073220131630	4	13314AB7680FPM715	111FJFF731	003601313038509032312AJ0385
2308065123080705	4	12141AB7680FP	75160PF731	100101216123500211122CJ0235
2308082623080930	4	12141AB7680FP	11230PF731	000431331123501111122AJ0235
2308101623081130	4	12141AB7680FP	11230PF731	1005013311235012111220J0235
2608080126081100	1	12141AB7680FP	111FJGF731	0003013130238030112118J0238
2608090126081015	2	12141AB7680FP	111AAPF731	000251214123801211211AJ0238
2608094126081300	3	12141AB7680FP	1422DQF731	101001331123803311211FJ0238
2608120126081600	1	12141AB7680FP	111FJGF731	100401313023804011211CJ0238
2708073127081100	2	12141AB7680FP	111FJGF731	100701313023903511211AJ0239
2708120127081600	2	12141AB7680FP	111GSGF731	1008013130239040112118J0239
2908080129081200	2	12141AB7680FP	14429GR731	100801313024104011222FJ0241
0411192104112330	1	12241AB7686FPM237	14310GF731	100421313030804220311QJ0308
0810180108102400	4	12242AB7686FP	14700PF731	002401224228106020222K80281
0810220108102400	1	12242AB7686FPS618	14700PF731	000201331228102020222J80281

Fig. 8 -- Combat damage 80-80 listing.

(Note that most damage is discovered by the ground crew as indicated by the "W" code "7". How far is how far action code 73; ID is Julian Date; ET is Elapsed Time.)

NOT REPRODUCIBLE

Average fix time, each system
Number of sorties battle damaged
Systems most frequently affected.

These summaries, of course, should be contrasted to the totals and averages of the entire sample from which the battle damages were drawn. In addition, it is often interesting to isolate the associated operations data to determine locations, altitudes, and conditions under which the damage occurred.

STATUS ANALYSIS

The concepts and intent of status reporting is good: to provide an index of emergency readiness of a unit. In practice, the usefulness of the information has fallen far short of the intent, and only the naïve assume that much meaningful information can be obtained from the status data analysis. There are three major reasons for this inadequacy.

First, inaccurate recording is tolerated. Foolish indeed is the unit commander who forwards an OR rate of less than 72 percent; censure is inevitable, so reports are falsified. Second, our experience has been that it is nearly impossible for the typical job control to account accurately for the status of each aircraft in a squadron.

Third, the current status codes militate against getting meaningful information. The two largest contributors to non-OR conditions are unscheduled maintenance and NORS. Since the unscheduled maintenance code has precedence over the NORS coding, no true measure of each is obtainable. This procedure results in a well-known method of controlling the reporting, which is seen in the following.

Assume that an aircraft is down for three NORS-G items. If job control wishes to reduce the amount of NORS-G time, it merely assigns some unscheduled maintenance to the aircraft. While this is being accomplished (preferably across 12 o'clock when the NORS-G counts are made), the aircraft is coded as being in unscheduled maintenance. Thus there is an automatic reduction of the NORS-G accounting. The reverse is also possible.

Because the status system is so unsatisfactory, we have repeatedly attempted to eliminate it from the recording system. Thus far we have met with no success. The data have become so traditional that they are impossible to eliminate. Our solution is to get them as painlessly as possible. This is done with the following routine.

Select the data having a 3 in Col. 80, using Compute Elapsed Time. Run with Analysis of Variance.

Sort, control	Major	Col.	80	card code
	Minor	Col.	26	status code
	Variable	Cols.	70-72	elapsed time

Only the entries under "Totals" are considered. These show the total aircraft hours lost to each of the various status codes. If desired, these entries are divided by the possessed aircraft hours (airframes x days x 24 hours) to obtain the percentages of lost hours. The OR rate is calculated as follows:

$$\frac{\text{Total hours possessed} - \text{total hours lost}}{\text{Total hours possessed}}$$

The following is offered for those interested in obtaining a more accurate analysis.

1. To obtain true unscheduled maintenance downtime, select the red X items, combine with the sortie records, and process through the analysis sequence. Sum gross recovery times.
2. To obtain the true phased and hourly inspection data, see section on phased inspections.
3. To obtain true NORS-G, use the supply 360 data.

These three generally account for better than 95 percent of status downtime. The additional elements, if desired, can be obtained by analogous processing (e.g., select the 797, 798, 801, and 802 codes to obtain tech order accomplishments). Since status reporting is scanty for other than the three items mentioned, use the status analysis to direct the effort.

Despite this pessimistic discussion, there are some interesting ideas that have resulted from status analysis. Two of these are not well known and hence are but little understood.

First, each aircraft TMS has a basic OR rate determined by its reliability-maintainability characteristics. For example, the F-4C has an average of three write-ups per sortie, each job taking approximately two hours. Obviously, the F-4C basic OR rate must be much less than the A-37A which averages 0.50 write-ups per sortie, each job requiring approximately an hour. Hence, for the same sortie rates, the two aircraft cannot possibly have the same basic OR rates. This introduces the second factor.

Each sortie exposes the aircraft to a possible malfunction. Consequently, the more sorties an aircraft flies in a given period, the greater its downtime will be for unscheduled maintenance and scheduled inspections. Hence, the OR rate will be reduced when sorties are increased. This is because the possessed hours are a constant. The result is a negative correlation between sortie rates and OR rates. Hence, command insistence on 72-percent OR for all aircraft under all circumstances is not meaningful.

If status coding is to be continued, which seems inevitable, the only meaningful approach is to establish norms based on the TMS of the weapon at various sortie rates.

BASE SELF-SUFFICIENCY

The completely self-sufficient base is one that repairs 100 percent of the reparable parts authorized for local repair. The objective of the self-sufficiency program is to make the unit autonomous in an emergency. For a number of reasons--lack of parts, lack of equipment, lack of skills, to name a few--100-percent self-sufficiency is frequently unobtainable. The base self-sufficiency analysis is intended to reveal the reasons why.

Whenever a reparable part is generated, an AFTO form 211 is completed. Copy 1 normally records the flight-line action. The remaining copies are used to control the repair sequence. Copy 2 is used by Materiel Control to handle the bookkeeping resulting from the supply-maintenance interface. Copies 3 and 4 are used to record the disposition of the reparable. Copy 3 is used to record the inspection-test-and-checkout of the reparable. If the shop repairs the unit

during bench-check, copy 3 is completed and copy 4 is destroyed. If the bench defers the repair, copy 3 is used to record only the check and inspection action. When the unit is repaired, copy 4 is completed, recording only the repair action.

Analysis of the self-sufficiency problem is slightly complicated because it is often expedient to set up a limited "assembly line" processing in which a number of units are processed at one time. In this instance only one document is completed. The "Units Produced" block contains the total number of items repaired. Because we are generally more interested in the number of units than in the number of man-hours, units produced is generally used as the variable.

Certain action taken codes are restricted for the recording of the bench actions. These are as follows:

- A--Bench checked and repaired
- B--Bench checked and serviceable (799)
- C--Bench checked and deferred
- D--Bench checked and transferred to another bench (used by Forward Operation Bases)
- 1--NRTS (not reparable this station) the repair is not authorized
- 2--NRTS no equipment, tools, or facilities
- 3--NRTS lack technical skills
- 4--NRTS lack of parts
- 5--NRTS excessive backlog
- 6--NRTS lack of technical data
- 7--NRTS excess to base requirements
- 9--NRTS condemned

The NRTS codes indicate the reasons for the non-repair.

Most often the analyst wants to summarize the bench actions for each work center for each month. These summaries can then be compared with the previous month's data to determine trends. Although occasionally there is interest in the number of man-hours consumed by bench actions, most frequently there is concern with the disposal of the units. Hence the units-produced entries are generally used as the variable.

The simplest way of obtaining a first approximation is to instruct the computer operator to "select, from the off-equipment file (66-1 data), those records containing a 3 or a 4 in Col. 80".

Sort, control	Major	Cols. 28-32	work center
	Minor	Col. 51	action taken
	Variable	Cols. 56-57	units produced

Process with Analysis of Variance. Since we have used units produced as a variable, the unit counts will be shown in the "Totals" column (the "Means" column will show the average number of units processed per 211 document). See Fig. 9.

In monitoring base self-sufficiency, three sets of action taken codes are scrutinized most closely:

1. Repaired (desirable).
2. Serviceable (too many of these may indicate lack of adequate troubleshooting).
3. 2-6 (inclusive) not repaired because of management inadequacies.

Comparisons may be made on two base-lines, either the percentage of total items processed, or the item counts prorated by sorties flown. Either base may be used as the base-line when processing the data with the Chi-square program.

FINDING THE SHORT RESOURCE

The perfectly balanced weapon system is not unlike the classical one-hoss shay in that it has the exact proportion of resources required to meet its task. This implies that the balanced system has exactly the right number of pilots, maintenance technicians, supplies, AGE and so on for its program; neither too few, which degrades mission effectiveness, nor too many, which is needless expense.

Unfortunately, because of the shifts and oscillations of changing mission requirements, rotation of personnel, and fluctuating demands, it is rare that the typical unit achieves a reasonable approximation of balance. Inevitably, when stress is placed on the system, it is discovered that one or more of the resources is insufficient to meet the increase in mission needs. It is particularly painful when this discovery is first made in a combat setting. Hence a means is needed of unearthing the short resource to fill the hiatus, when possible, or when impossible, to insure that it gets priority management.

SAMPLE FREQUENCY DISTRIBUTION									
BENCH REPAIR ACTIONS		UNITS PRODUCED		WORK CENTER		TAPE		NO SORTIE COUNT	
01 28-32		51-51		56-57		SHIFT 1		A-----D-E----- ON	
2--		2--		1--		C		1	
SIGMA		.8		.9		1.0		1.1	

To this objective (resource utilization determination), fractioning the data by the sortie is without peer, since it is the sortie that causes resource consumption. This is seen first by the provocation of demands for a resource, which is followed by the use of the resource for some period. So it follows that if the demands are increased, or if the length of the utilizations becomes excessive, resources will be insufficient to meet the system requirements.

Increases in resource utilization result principally from three factors: increases in sorties, increases in malfunctions, and increases in job durations. Lacking computer simulation capability, we cannot predict resource needs when such increases occur. What we can do, however, is isolate resources currently in short supply and use this list as a basis for predicting what might happen. Note that no technique (simulation or otherwise) will ever predict what will happen. For example, suppose the question arises: What would happen if I go from an average one-hour sortie to an average two-hour sortie? It would be natural to guess that no change will take place in the landing gear write-ups (its usage is independent of sortie length), while engine write-ups should double. The guess would probably be wrong. As a matter of interest, one sample of combat data in which sortie length increased from 1 to 1½ hours showed a decrease in all resource utilization.

Admitting, then, that in many instances it will be impossible to predict what will happen, there is still a need to be able to identify the short resource quickly to insure that it gets special management attention. For certain, we will wish to look at four resources: aircrews, maintenance personnel, AGE, and supplies.

Aircrews

Aircrew information may be obtained from two sources. First, extrapolate the current aircrew determination rules--for example, pilots will fly a maximum of 20 combat sorties a month. This rule provides for nonflying duties, R&R, and so on. Divide the projected monthly sorties by 20 and compare with the number of certified aircrews. Note that when an aircrew requires more than one man, there is often an

imbalance, i.e., an excess of navigators or flight engineers. Hence the determination is made on intact aircrews, and the short resource is the one that determines the aircrew count. Note that there are back-up resources: the squadron commander, the director of operations, and others, who can on occasion be called upon to fill out an aircrew.

Second, review the aircraft deviation data (select 80=H, format U, sort on deviation code Cols. 7-8, process with DEVDEG). Check the verbal information on late takeoffs and operations cancellation to determine whether these were caused because aircrews were not available. If so, review the daily sorties scheduled and flown data (Col. 80=2) (format M) and the sortie comments (Col. 80=B) (format P).

Maintenance Personnel

In predicting maintenance personnel availability, the preferred first step is to scan the delay data in its entirety. This is done by selecting the Col. 80=1 (format L) records and processing them through Compute Elapsed Time. These are then processed with Analysis of Variance. See Fig. 10.

Sort, control	Major	Col. 79	squadron
	Minor	Cols. 53-55	delay code
	Variable	Cols. 70-72	elapsed time

The N and totals columns show the relative proportions of delays for each of the following codes:

MEN	personnel
AGE	aerospace ground equipment
AWP	parts

To determine the particular shops causing the delays for personnel, select the records containing MEN, Cols. 53-55, and list 80-80. The delay-causing shops will appear in Cols. 62-66.

This set of procedures gives only a coarse overview of the problem. For a more detailed picture, follow the regular manpower analysis sequence, scrutinizing closely those instances where utilization rates approach and/or exceed 100 percent. It is understood that the analyst will also determine whether or not excessive man-hour consumption is

COMPARISON OF DELAY DATA	ELAPSED TIME	TEST SQUADRON	TAPE 2582	CODE--	A	SPOTIF COLUMN
01 30-18	32-55				SWITCHES A-----D-----	ON
01 30-18	32-55					

[illegible]

ANALYSIS OF VARIANCE

	SUM SQUARE	DF	MEAN SQUARE	F
BETWEEN	3359.4329	10	335.9433	37.0443
WITHIN	63018.3512	6949	9.0687	
TOTAL	66377.7841	6959	9.5384	

Fig. 10 -- Distribution of delay codes

(Sample 2-5 now coding errors). The "TOTALS" column provides the critical information. Two entries, ETR and WSE, account for two-thirds of the delays. Shortage of personnel, code MEN, shows only a minor defect.

due to injudicious shift assignment. This is also determined from the manpower analysis sequence.

A final source of information is the AFM 66-1 bench repair actions (copies 3 and 4 of the 211 actions). Select the Col. 80=3 and Col. 80=4 from the 66-1 data. These should be sorted:

Major	Cols. 28-32	work center
Minor	Col. 51	action taken
List 80-80		

The action taken code "3" NRTS, lack of technical skills, indicates a proficiency level beyond the capability of the particular shop in question.

Aerospace Ground Equipment

Getting a complete and satisfactory set of AGE utilization data is both difficult and costly. Certainly we do not recommend continuous recording as a method of choice. For those wishing to try getting a sample, the methodology is described in Volume II. The following is offered as a less costly, but not so satisfactory solution to the problem.

The 300 form provides for the inclusion of a "local use" block, which is generally used to record the man number for a maintenance action. This local use block can also be used to record the cause of the aircraft delay; i.e., when the maintenance cannot be completed because of lack of AGE, the delay record is created and the specialist enters the AGE noun or mnemonic. It is not practical to establish a uniform list of identities, nor is it necessary since the number of records is small.

As a first determination, select the delay data (Col. 80=1) pertaining to AGE (Cols. 53-55) and list 80-80. Inspect Cols. 41-45 to determine the types of AGE involved and the start and stop times of the AGE to see if the time of day gives some clue.

If the above inspection warrants a more detailed exploration, additional information may be derived by putting the delay data through the manpower utilization sequence. Get the touchdown summary data as usual (Col. 80=A). From the AGE shop, get the daily AGE

availability and convert to Col. 80=E (manpower available) record (format W). This is most easily done by keypunching directly into E format. If so desired, it can be keypunched in Col. 80=5 (format E) and computer edited to produce the Col. 80=E data. The delay data converted to W formats (Col. 80=N) are produced by processing the delay data through Hourly Frequency Accumulate and Select. To do this, the various entries in Cols. 41-45 of the Form 300 data must first be recoded to agree with the nouns selected for entry in the E cards. For example, the various entries indicating hydraulic mule are all recoded as "HMULE" on both the E and N cards.

In using the Hourly Frequency Accumulate and Select program to process delay data, Cols. 1-6 of the control card are punched 041045 (the location of the AGE code), Cols. 7-12 are left blank, Cols. 79-80 are punched E1. The data are sorted as follows:

Major	Cols. 41-45	AGE code
↓	Cols. 11-12	month
↓	Cols. 9-10	day
Minor	Co's. 13-16	hour-minute

The A, E and N cards are then processed through the Manpower Utilization program, and the output scanned for clues. Note that here the "utilization" is now a picture of the nonavailability of AGE, presumably because the demand has exceeded the availability level.

As with manpower, the bench repair data may be scanned for the action taken Code 2 (NRTS--lack of equipment, tools or facilities). To do this, select the 66-1 data having a "3" or "4" in Col. 80.

Sort	Major	Cols. 28-32	work center
	Minor	Col. 51	action taken
	List	80-86	

Supply

The short supply resource is the most difficult of all to isolate. This is because the maintenance specialist has a number of alternate mechanisms for clearing a write-up other than substituting a specific black box drawn from supply: he can fix the box; he can cannibalize from another aircraft; he can replace the box with the next higher

assembly; or, in some instances, he can let the write-up stand. Thus a supply demand is rarely at a one-to-one ratio with the write-ups. Hence there is no reason to presume that doubling the program will double the supply demands. In Rapid Roger, for example, the supply demand rates decreased as the sortie rates increased, rather than vice versa, as might have been expected. Again, there was strong evidence that the sortie type was having an effect. (One unkind individual suggested that the decrease was caused because maintenance personnel were learning not to depend on supply.) Unfortunately, until provision can be made to provide the equivalent of the RAND Base Stockage Model at unit level, the isolation of the short supply resource will be difficult.

Despite this, we need to be able to do something besides wring our hands in anguish. Fortunately, something is available--the supply 1050 system that makes accessible all sorts of interesting summaries, accounts and reports. One of the more interesting is the AFS-52 report which gives, on a daily basis if so desired, the items causing NORS grounding. There is one limitation, however; the reported item may be the one causing the NORS-G condition, or it may be the bits and pieces that are needed to repair the item. If it is necessary to make this distinction, check with the work center that does the repair.

One of the unfortunate shortcomings of the NORS codes is that they apply almost exclusively to safety-of-flight items. No cognizance is given for a defective weapon release problem, but because no safety of flight is involved, it is not identified as a grounded aircraft. Hence there is no way of identifying the shortage of critical (i.e., mission essential) items. This defect shows itself most fully in the SEA data; many sorties have to be scrubbed or else flown in degraded combat status because no provision has been made to include the mission essentiality factor.

Providing the analyst has the time, we suggest he first construct a list of the type of sorties his particular outfit will be required to fly, and from this, using the assistance of knowledgeable maintenance people, construct a list of parts that are mission essential to each sortie type. Our sortie type analyses of both Skoshi Tiger and Rapid

Roger data indicate, unfortunately, that the difference that the differences that because of sortie type cover the entire aircraft, not just the weapons package. However, two or three sortie types (i.e., regular, deep interdiction and escort) are generally all that are needed to cover most situations. It can be expected that a good bit of exploration and analysis will be required before the final list of sortie types is firm. To start this, do a complete 7- and 8-card analysis comparing data by sortie type. Combine similar samples (i.e., those samples showing homogeneity of means and variances). The object is to find the smallest number of unique sortie types. These are used to establish the mission essential items.

The mission essential evaluation, unfortunately, is not complete and sufficient for all purposes because of the flying rules. For example, the local rules may say that on a certain type of mission two (or one to three) of four operational inertial navigation systems are sufficient to fly the mission. In contrast, these same local rules may say that on another mission type all four inertial navigation systems must be operational. This is not to imply that such decisions are capricious; on the contrary, they are almost inevitably the result of some catastrophe or near catastrophe which has resulted in some serious reevaluation. Whatever their origin, these rules do complicate the problem of determining the short resource, since not only is the question of the type of sortie involved but also the mission structure.

Despite the complexity imposed by the mission composition, our analyst has no recourse except to compute for all mission types. The problem is identical to the redundant system problem on one aircraft.

III. ANCILLARY CONSIDERATIONS

NOTES ON ANALYSIS OF VARIANCE AND CHI-SQUARE COMPUTATION

The Analysis of Variance displays (n. 25, Volume II) are extended to -2 and 5Z with a reason: All maintenance data are markedly skewed. This distribution of observations is so skewed that means are typically located near the 70-75th percentiles, rather than the 50th percentile of normal distribution. The effects of this skew play havoc with the variance. The problem is worsened because the sample sizes (N) are always unequal. This combination makes statisticians shudder, and with reason. Since skewed distributions and unequal sample sizes are a way of life, there is a need for some comment on how to live with these situations.

First, as indicated by the Donaldson study,^{**} the F-test is exceedingly robust with respect to both type I and type II errors for some kinds of distributions.^{***} For lognormal and exponential distributions (which are similar to many distributions of maintenance parameters), the F-test is conservative^{****} with respect to both types of errors. This conservative feature exists for any distribution with positive skewness and kurtosis. This indicates that the F-test does very well in identifying random variation among the sample means: If the F-test is not significant, the distribution is homogeneous; that is, the two samples being compared are assumed to have the same characteristics.

Second, the Analysis of Variance program displays N_s , means, and associated variances. The latter facilitates testing discrete cases

^{*} To follow this discussion, some knowledge of statistics would be useful. A recommended text is W. J. Dixon and F. J. Massay, Jr., Introduction to Statistical Analysis, 2d Ed., McGraw-Hill Book Co., Inc., New York, 1957.

^{**} T. S. Donaldson, Power of the F-Test for Nonnormal Distributions and Unequal Error Variances, The RAND Corporation, RM-5072-PR, September 1966.

^{***} Type I errors reject a hypothesis when it is true; type II accept a hypothesis when it is false.

^{****} A conservative test is one that gives smaller errors than would occur if the distributions are normal.

within the sample. Thus one might isolate a particularly interesting pair of means, and compute a t-test between the two to find the difference between means. Third, one can test the difference between variances by dividing the larger by the smaller. This gives a pair of tests, one on means (t-test) and one on variances (F-test). This is not, unfortunately, the equivalent of twice as many tests because the mean and the variance are related. Fourth, an additional test is provided; the means columns are tagged with the traditional one, two and three asterisks based on the harmonic mean of the sample. This helps circumvent the problem of unequal Ns. The tags are based on standard errors expressed as 0.05, 0.01 and 0.001 levels of significance.

There are, then, a number of tools available for dealing with the problem of errors in skewed distributions. There is also another test that could be used: the nonparametric Kruskal-Wallis one-way analysis of variance. Since this is distribution free, the skewness is not a problem. We are currently comparing this with the conventional one-way analysis of variance. If it turns out to be better, we shall program it for the 1401.

Among much of the elapsed time data is a human intervention factor that is a major contributor to the inequality of the variances. This is seen in Table 5. The last line of the table gives the ratio between

Table 5

VARIANCES OF FOUR DIFFERENT MAINTENANCE MEASURES

Gross Turnaround	Delays	Turnaround	Man-Hours	N
12,905.99	9973.71	258.79	2434.30	454
847.78	337.80	176.94	2485.78	563
3,353.14	1554.27	402.68	4423.89	139
3,834.20	2567.15	233.50	2646.21	844
2,359.68	1050.06	339.72	2778.45	503
3,555.31	2307.50	259.48	2765.30	1308
260.10	43.90	107.25	1361.00	870
High/Low	49.30	224.80	3.80	3.20

the largest and smallest variance. Two of the measures (gross turnaround and delays) are unacceptably high. The other two, net turn-

around and man-hours, are small enough to lead us to conclude that a reasonably valid F-test could be obtained. (As a crude rule-of-thumb, if the N is greater than 50, and the variance range less than 10 to 1--preferably less than 5 to 1--a satisfactory F-test can be obtained.)

There is an interesting observation: gross turnaround is comprised chiefly of two elements--net turnaround and delays. The length of the delay, however, is purely a human intervention factor. The delay ends when job control decides to start the next job. Note that it is the presence of delays that causes erratic variance behavior. In contrast, net recovery is essentially a hardware characteristic. Its duration is principally a function of the weapon's inherent characteristics. Man-hours is also a hardware oriented quantity--net fix-time multiplied by team size. The interesting observation is that the human intervention factor seems to intrude a turbulence into the comparatively stable hardware characteristics.

A similar set of comparisons is made on the same data to determine the effects of removing the NORS and the phased inspection data, as shown in Table 6. Here, the removal of the NORS data substantively

Table 6
NORS AND PHASE EFFECTS

All Data	NORS Out	Phase Out	Both NORS and Phase Removed
12,905.94	205.71	13,239.12	185.99
647.78	222.90	899.03	207.70
3,353.14	180.56	3,188.27	89.33
3,834.20	446.21	2,705.19	306.50
2,359.68	232.57	1,090.13	155.90
3,555.31	1523.09	2,587.01	1447.61
260.10	187.82	172.76	131.32
High/Low 14.80	8.20	18.20	15.10

improves the variances; but the removal of the phase data worsens the picture. This is interesting because the phase turnaround analyses reveal a particularly maladroit handling of the phase turnarounds which ranged from a high of 9 to a low of 1 1/2 days. This latter figure is the only acceptable one, and it occurred in only one of the samples.

To those not familiar with NORS data, the chief element in the NORS turnarounds is the "hangar queen." All the grounding NORS items are consolidated against one or more aircraft (queens), which may stay grounded for days or weeks at a time. Terminating the NORS turnaround is also a human intervention factor. The Chief of Maintenance becomes weary of the hangar queen and orders it ended. It is refurbished by cannibalizing from other aircraft.

There are advantages and disadvantages to both consolidation and cannibalization. Consolidation is simple, but prolonged nonusage of the aircraft causes problems in its hydraulic and electronic systems. Cannibalization puts many aircraft out of action, each for only one or two items. Either way you lose. As a general statement, it is better to consolidate, despite the additional cost in man-hours if the sortie/aircraft ratio is high. If manpower is short, the reverse is true.

CHI-SQUARE

The Chi-square program complements the Analysis of Variance program. Whereas analysis of variance statistically tests quantitative interval data (man-hours, elapsed time, and so on), chi-square analysis serves the same function with frequency count data (write-ups per sortie, break-rates, abort rates, and so on).

In making the chi-square determination, the switch D setting must correspond to the type of data being processed--either dichotomous or nondichotomous information. The chi-square computation differs with each type. Dichotomous data require Yes-No answers; the system broke--Yes? No?; the aircraft aborted--Yes? No?. In statistical terms such data take the form $p=1-q$ (p =yes, q =no). The proper computation of dichotomous data includes the computation of the nonoccurrence frequencies. Thus, in the case of system break-rates, the final chi-square includes a computation based on the number of times the system breaks and also one based on the number of times it does not break. This combined computation is automatically produced when switch D is "off".

Nondichotomous data are not of the $p=1-q$ form. For example, "How many rounds hit the target in this strafing pass?", or "How many

write-ups occurred on this sortie?" Such data take the form p-q, and nonoccurrence frequencies must be excluded from the chi-square computations. The upper switch D setting is "on".

The strafing pass provides an excellent illustration of the distinction between dichotomous and nondichotomous data. If the method of scoring is "Yes, I did hit the target," or "No, I did not hit the target," the data are in dichotomous form and the chi-square computation must include the nonoccurrence counts. However, if the method of scoring is, "How many rounds did I get in the target?", the data are not in dichotomous form and, accordingly, the nonoccurrence frequencies are excluded from the computations.

Since most measures are frequency counts (the majority of quantitative data fall under the aegis of either hours or distances), the Chi-square program will be in frequent demand. To reduce the labor in getting the data into useable form, the Analysis of Variance and FREQ programs have been modified to output the required records. The simplest is FREQ. To use this, sense for the desired majors and minors. Set the appropriate switches to produce the desired output.

Since FREQ does not include the base-line data, these must be added to the output records. If the record is on cards, they may be keypunched, the automatic duplication feature greatly facilitates this process. Since the record volume of the Chi-square program input is quite small (a complete file of break-rate trend data rarely exceeds 100 records), card input is almost always used because of its greater flexibility.

In using the Chi-square program, the following fields are always sensed:

- Base-line (sorties flown, items attempted)
- Item counts (write-ups, breaks, demands, hits)
- Minor code (3-character data identifier)
- Major code (sample identifier)

The item counts are always given as whole numbers, never as decimals or multiples of 10. Violation of this rule causes erroneous chi-square calculations. In contrast, the base-line data, which are used only

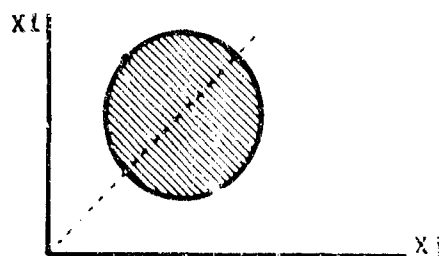
to compute the theoretical frequencies (by prorating), may be scaled in any manner desired. Since sorties flown is by far the most frequently used base-line, the program assumes that the base-line data have no decimal place.

The reader may wonder why chi-square does not have as many limitations as analysis of variance (e.g., unequal samples, unequal variances, nonnormality of distribution). The reason is that chi-square belongs to a class of statistical techniques called nonparametric or distribution-free methods. These have been developed specifically to circumvent the restrictions of the parametric methods. In general, the nonparametric methods are not quite as efficient as the other. They are, however, simple to use and understand and are free of limiting constructions.

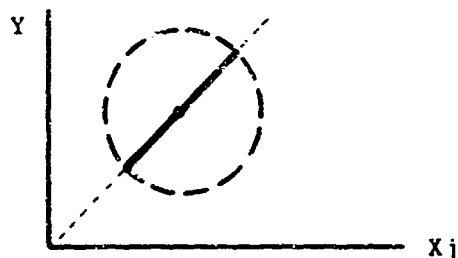
MULTIPLE CORRELATION ANALYSIS

Those few people who have had a chance to apply multivariate techniques to maintenance data realize what powerful tools these methods can be. There are, however, a number of restrictions on the use of these techniques, and the nonknowledgeable find it comparatively easy to make some exceedingly absurd statements. We are attempting here to offer a somewhat less elegant approach that can be adapted to the small business computer. Our objective is to give the analyst a means of winnowing his data, isolating those elements that can profitably be explained in more detail. The method stops short of computing a full-blown regression equation, but it does point out the most likely member for such an equation. Our objective is to relate the dependent variable, Y , to as many independent variables, X_i 's, X_j 's, as are useful. The correlation matrix, thus, is scrutinized to isolate independent variables that correlate low with each other and high with the dependent variable.

To illustrate the above, consider first the definition of a correlation area $X_i X_j$ in which $X_i X_j = 0$; that is, X_i and X_j are not related:

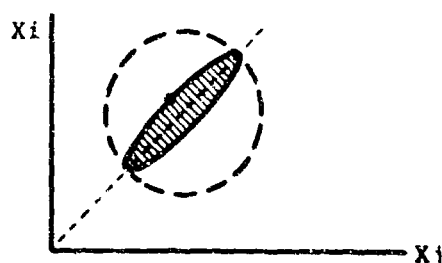


Then consider the correlation area of YX_j , where there is a correlation of 0.90:



Had we constructed a three-dimensional model of the relationships, it would have looked like the combination of our two two-dimensional models--a discus-shaped object with the Y axis running through it like the spindle of a top. The direction that the spindle points to is well defined because of the circular shape of the $X_i X_j$ plane. The plane is determined by rotating the discus to its smallest two-dimensional view (i.e., directly edgewise); the Y axis is at right angles to the smallest two-dimensional view. Since the object is discus-shaped, the position of the Y axis is readily discovered.

Now consider the case when $X_i X_j$ are highly correlated (say 0.80):



Then construct an imaginary three-dimensional model as before. The result is the shape of a slightly flattened cigar. Now when we attempt to define the $X_i X_j$ plane by rotating it to the smallest two-dimensional view, we can locate this plane only with great difficulty; hence we cannot be sure just where the Y axis points. And it is possible that the smallest amount of data error could materially alter the definition of the $X_i X_j$ plane and hence the location of Y. Thus we seek to find independent variable X_i 's that are only slightly related to each other but highly related to the dependent variable.

This is the essence of the technique: the program first computes the matrix of correlations and then selects the highest correlation

between the items selected as the dependent variable (Y) and X_i . It checks the correlation between X_i and all other X_j 's. The analyst is now in a position to choose the independent variables that meet the criteria indicated above.

VARIANCES, SIGMAS AND NORMALIZATION

In the short space of this Memorandum, it is impossible to discuss adequately the behavior of stochastic phenomena and how to control (measure) them. Nevertheless, the individual attempting to analyze weapon system behavior needs to have some understanding of the nature of the stochastic beast.

The word stochastic (which will not be found in most dictionaries) implies variability. The fix time of the radar system varies. It varies over enormous dimensions from as little as five minutes (in the case of circuit breaker overloads) to several days. And, although the average fix time is, say two hours, the variability above and below this average is tremendous. Because of such variation, it seems impossible to determine whether or not the radar fix times have changed. Certainly, only the very brave or very naive would attempt to make definite statements about such a vacillating phenomenon. Fortunately, thanks to the efforts of a number of people (generally referred to as theoretical statisticians), the possibility of making sense of the phenomenon is more optimistic than it appears.

The first optimistic note comes when it is understood that, despite the wide spread of the fix time distributions, the means of the various samples vary over a much smaller range. For example, a series of weekly or monthly average fix times will seldom fall more than 20 minutes above or below the grand mean of the data sample. (It is worth an aside to note that this restricted ranging of the sample means is of small consolation to job control personnel who need to know the ETIC (estimate time to in-commission) of a particular system on a particular aircraft.)

The heart of the entire statistical determination concerns determining whether the means of the weekly-monthly samples have shown only the normal random variation characteristic of all stochastic phenomena

or whether the variation of the means has exceeded the bounds of propriety, as the result of some extraneous force event. For example, a big influx of trainees might be expected to cause sharp increases in repair times. If it is indeed true that trainees do take longer fix times, then we should see the mean of this data sample swing outside the bounds of random variation. The way of determining this "out-of-boundedness" is one of the functions of statistical testing. The heart of all the testing involves determining the variance, which is a measure of the amount of spread or range of a data sample.

The computation of a sample variance is simplicity personified. Imagine a sample of radar fixes with a mean of 2.0 hours. Next, take the list of raw scores (individual fix times) and assume the first is 4.5 hours. Get the deviation by subtracting the first raw score from the mean ($4.5 - 2.0 = 2.5$), then square it ($2.5^2 = 6.25$). Do this with each raw score. Add up the list of squared deviations to get the sum of the d^2 (written Σd^2). Obtain the average d^2 by dividing through by the number of raw scores--more properly, divide through by one less than the number of raw scores. Note that the squaring process eliminates negative signs. We now have the sample variance. An example illustrates the entire process.

	Raw Score	Deviation	d^2
	4.5	2.5	6.25
	0.5	-1.5	2.25
	0.5	-1.5	2.25
	1.5	-0.5	0.25
	<u>3.0</u>	1.0	<u>1.00</u>
Sums	10.0		$\Sigma d^2 = 12.00$

$$\text{Mean} = 10.0/5 = 2.0.$$

$$\text{Variance} = 12.0/4 = 3.0 \text{ (variance} = \Sigma d^2/n-1).$$

The variance of 3.0 combined with the mean of 2.0 gives us a complete description of the sample in that we have its "most representative score" (mean) and an index of the spread of the data around that mean. This statement is true only for nonskewed distributions.

Another common measure of sample variation is the standard deviation, also called sigma. This is the square root of the variance, in this instance $\sqrt{3.0} = 1.72$. Note that this takes us almost back where we started. We took the deviations, squared them, got the "average" squares, and then took the square root of this average. Hence our standard deviation is, in a way, the most typical deviation.

In illustrating the concept of variance, we used a sample and its mean. It is also possible to take a sample of means and treat it the same way. For example, we might have the monthly means for a six-months' sample of radar fix times:

Means	Deviations	d^2
2.0	0	0.00
2.3	0.3	0.09
2.1	0.1	0.01
1.7	-0.3	0.09
1.5	-0.5	0.25
<u>2.4</u>	0.4	<u>0.16</u>
$\Sigma = 12.0$		$\Sigma d^2 = 0.60$

Mean = $12.0/6 = 2.0$.
Variance = $0.60/5 = 0.12$.

Given the mean, the variance, and the tests for nonrandomness (generally referred to as nonhomogeneity), the various specific statistical tests are quickly made. For example, the famous F-test in analysis of variance is computed by dividing the mean variance (shown in the second sample) by the sample variance (within variance), and is computed much like the first sample above.

It is helpful to know one more concept: Normalization is the process of expressing the sample data in terms of their standard deviation. This is done simply by dividing each unsquared deviation by the standard deviation. For example, a deviation one sigma above the mean would result in a normalized score of 1.0; a score of 1.5 sigma below the mean would normalize to -1.5. If we do this to a number of samples, we have now reduced them to common terms and can properly make a number of peculiar sounding statements such as "John

is taller than Mary is musical," meaning that John's normalized height measure is greater than Mary's normalized musical ability measure. Most tests of mean differences and correlation use this normalization process.

To summarize, the capability to be able to deal with stochastic phenomena is provided by being able to compute sample variance. Since almost all maintenance, operation, and supply data are stochastic in nature, the ability to compute the variances is not a trivial element.

ON-SITE ANALYSIS

In the exercises prior to Rapid Roger, the data had always been gathered and edited at the site and, at the end of each exercise the analysis was conducted elsewhere. It was the experience of the Skoshi Tiger exercise that convinced us that this method had serious shortcomings in that we were discovering, through the analysis process, a number of unknown factors. At this late stage there was no opportunity to determine through local inquiry the details or to take steps to control any undesirable element that the analysis revealed.

Although plans for the Rapid Roger exercise did not include on-site, on-going analysis (specifically, the plans called for collecting and editing in the theater with the analysis to be done at Eglin Air Force Base), during the progress of the test it became apparent that such procedures were desirable and feasible using those analysis programs that had been developed to date. Our brief experience in the theater was sufficient to demonstrate the overwhelming advantage of on-site analysis. The contrast was particularly marked during the post-exercise analysis at Eglin where, as usual, new factors were unearthed and, once again, we were faced with the awkward problem of how to understand and what to do with the new information.

It should be clearly understood that what has been called on-site evaluation does not imply analysis in vacuum. The findings must not and should not be kept hidden by the evaluation team. Rather, any interesting, unusual, or puzzling findings should be taken to the location and discussed thoroughly with the knowledgeable personnel:

peculiar NORS behavior is discussed with Supply, Materiel Control and Job Control; turnaround problems with Job Control; and break-rate data with pilots, debrief, and the associated work centers.

All of these people will have valuable additional pieces of information that materially contribute to understanding the phenomenon. Occasionally, and this is the part that needs to be probed repeatedly and consistently, they will come up with items of intelligence that cause a complete revision of the interpretation. For example, at one base a discussion revealed that when someone is building a mission, the lead aircraft is always selected from the A flight, while the remaining ones are always selected from the B and C flights. This means that one set of aircraft (the A flight) are always flown at constant throttle, while the others never are. Having this information enabled the analyst to determine whether the nonrandom selection process had an impact. It was the bull session that provided the information.

The point we are making is that the analyst may not remain in an ivory tower. He must spend considerable time pounding the flight-line, checking with the Tactical Air Control Center, Job Control, Materiel Control Operations, Supply, and the various work centers. He must absorb a tremendous amount of class knowledge from a wide variety of disciplines. This, in turn, means that, because of the tremendous complexity of modern weapon systems, his education will never end. For, truthfully, no one person could ever hope to absorb it all. This, of course, implies that the job will always be a good bit spicier than most.

THE HEURISTIC APPROACH

The activities of most computing centers fall mainly into either production or exploration. It is this production aspect that the layman thinks of, if he thinks about it at all, when he attempts to conceptualize a computer operation. The buttons are pushed, the tapes reel, the lights flash, and voila--out comes the answer. Not an answer, but the answer. And so it is with production works that a

standard program is used with standard procedures to output a standard product; the monthly report, the payroll, or the account summary. Production work is an excellent and efficient way of using a computer, and saves thousands of tedious man-hours daily. It is also very dull.

This is not the way it goes with analysis, however, which by its nature must be exploratory. True the lights flash and the tapes reel, but mostly what comes out is not the answer but an answer. In the analysis game, both with and without computers, what really occurs is a series of iterations during which the analyst gradually evokes a clearer and clearer picture of the phenomenon. To do this, he must take repeated slices through the data, each one intended to offer a new perspective. Cul de sacs (nonprofitable slices) are the rule, not the exception. The sequence is generally like the following.

Reviewing the problem, the analyst determines that a particular way of slicing the data will give him the truest picture. So he slices. But, as inevitably happens, this exposes to him some elements not included in his initial consideration. So he decides, if I now slice in this manner, I will understand the role of these new elements. So he slices anew. Eventually he comes to a point of diminishing returns: the new slices no longer give him sufficient additional information to be worth the effort or expense. This means he feels he understands the phenomenon sufficiently to meet the needs of the moment.

It is this iterative process, actually a series of hypotheses and corrections of hypotheses, that is and must be the analytical way of life, at least until we develop such a complete understanding of the interrelationship of all the elements of modern weapon systems that we can make a production process of the analysis. This, certainly, will not be in the next few years.

This distinction between production and exploration comes up in another manner. Computers are costly, and production work, because it is predictable, allows an efficient use of the computer. Analysis work is quite another goose. The analyst needs time to digest his last input before he can make a meaningful second pass. And the idea of the computer standing idle while the analyst thinks out his next step is enough to make most budget people shudder, and rightfully so. Consequently,

whether he likes it or not, the analyst must resign himself to the fact that he is going to have to sandwich his time between that of other computer users because the system cannot afford otherwise. By the same token the shuddering budget people must recognize and provide for computer analysis time, which by its very nature will always be a periodic demand.

This last paragraph, perhaps, takes us too far from our initial purpose--that of disabusing the beginning analyst of the idea that the process is a fixed, canned, one-shot affair. It is not. It never will be. In fact, our experience has been that the chap satisfied with the one-shot pass generally does not understand the problem.

Appendix A

KEYPUNCH FORMATS AND LIST OF FORMS AVAILABLE FOR RAND/TAC SYSTEM

For the reader's convenience, this appendix lists the forms included in Appendixes B through G of Volume I for the RAND/TAC system. Also included in this appendix are the Key punch Formats.

Operations Forms

CD form 101	Sortie Debriefing
CD form 101	Debriefing of Combat
CD form 101	Degradation Factors During Flight to and from Target
CD form 101	Degradation Factors During Combat
CD form 101	Combat Crewmembers' Comments and Recommendations
CD form 101	BDA
CD form 102	Joint Services Anti-Aircraft Fire Incident and Damage Report
CD form 103	FAC Poststrike Debriefing Checklist

Maintenance Forms

MIP form 305 test/	
RR form 300 test	
RAND form 300	Maintenance Data Collection Record
RAND form 302	Maintenance Data Collection Record
RAND form 303	Sorties Flown, Scheduled or Scrambled
RAND form 305	Aircraft Status Summary
RAND form 306	Manpower Availability
RAND form 307	AGE Utilization
RAND form 308	Mission Go
RAND form 309	Deviations/Degradations
RAND form 30D	General Purpose Information Record
	F-4C

Supply Forms

CD form 303	Record of Cannibalization
CD form 401 (Part A)	Demand Register
CD form 401 (Part B)	Demand Register
CD form 402	Receipt or Cancellation Register
CD form 403	NORS Register

Personnel Forms

CD form 200	Personnel Data Worksheet
CD form 201	Personnel Information Data
CD form 202	Supervisor's Information Data
CD form 204	Aircrew Experience Record

Facilities Forms

Form F-1	Airfield Facilities Survey--Monthly
Form F-2	Airfield Operations, Safety and Weather Survey--Daily
Form F-3	Motor Pool Survey--Weekly
Form F-4	Electrical Power Generation Survey--Monthly
Form F-5	POL Facilities Survey--Monthly
Form F-6	Munitions Facilities Survey--Monthly
Form F-7	Supply Facilities Survey--Monthly
Form F-8	Maintenance Facilities Survey--Weekly

Keypunch Formats

Edit Program Input

Format A	Debrief Summary
Format B	Form 300 (On-aircraft maintenance)
Format C	Sortie--Scheduled and/or Flown
Format D	Status Card
Format E	Manpower Available
Format F	AGE Utilization
Format G	Mission Go
Format H	Deviation/Degradation
Format I	General Purpose Comment

Edit Program Output

Format J	Debrief Summary
Format K	On-Aircraft Maintenance
Format L	On-Aircraft Work Delay
Format M	Sortie Flown
Format N	Sortie Scheduled, Not Flown
Format P	Sortie Comment
Format Q	Aircraft Status
Format R	Manpower Available
Format S	AGE Utilization
Format T	Mission Go
Format U	Deviation/Degradation Comment
Format V	General Purpose Comment

Program Output Summary Cards

Format W	24-hour Spread
Format X	Analysis of Variance
Format Y	RECSUM
Format Z	Frequency Count
Format AA	Off-Equipment (AFTO 211) Manhour

Program Control Cards

Format C1	Lag/Delay
Format C2	Analysis of Variance
Format C3	Aircraft histogram
Format C4	Table Loading Stopper
Format C5	Manpower Utilization Title Card

Keypunch Instructions and Formats (Continued)

Program Control Cards (Continued)

Format C6	Edit Program Gangpunch Master Card
Format C7	Display Program Date Select
Format C8	Display Program Tape Output
Format C9	Tape Input
Format C10	General Title Card
Format C11	Histogram Title Card
Format C12	Field Selector
Format C13	Complete Elapsed Time Program--Code Selector
Format C14	Frequency Count (FREQ) Field Locator Card
Format C15	Chi-Square Title Card
Format C16	Chi-Square Field
Format C17	Correlation Field Designation
Format C18	Correlation General Title Card
Format C19	Correlation Field Designation Table Stopper Card
Format C20	Correlation Independent Variable Test Control Card
Format C21	Analysis of Variance Header Card

Master Tables

Format M1	Work Center Master
Format M2	Tail Number Master
Format M3	2-Digit System Table
Format M4	Edit Program AGE Table

Clint Program Summary Records

Format R1	Aircraft
Format R2	2-Digit System
Format R3	Work Center

Combat Dragon Card Form 101 Operations Cards

Format CD1	Sortie Debriefing
Format CD2	Debriefing of Combat
Format CD3	En Route Degradation Factors
Format CD4	Degradation Factors on Target
Format CD5	Flight Crew Comments and Recommendations
Format CD6	BDA
Format CD7	Battle Damage Assessment Remarks

Combat Dragon Supply Edit Output Cards

Format CD8	Demands, Receipts, and Cancellations
Format CD9	Cannibalization Tape Format
Format CD10	NORS

Combat Dragon Supply Edit Input Cards

Format CD11	Demands, Receipts, and Cancellations
Format CD12	Cannibalization Card Format
Format CD13	NORS

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FORM 300 (ON-AIRCRAFT MAINTENANCE)[illegible][illegible]

EDIT PROGRAM INPUT

STATUS CARD

AIRPORT TAIL NUMBER		STATUS CODE										INTO STATUS		OUT STATUS		MWS UNIT (CODE)		MWS UNIT (CODE)		JULIAN DATE		CARD CODE	

FORMAT D

MANPOWER AVAILABLE

DATE		WOR. CENTER		AVAILABLE				FIRST SHIFT		SECOND SHIFT		THIRD SHIFT		CARD CODE	
AV	NO.	SHIFT	LEVEL	SHIFT	LEVEL	SHIFT	LEVEL	START	STOP	START	STOP	START	STOP	START	STOP
								HR	MIN	HR	MIN	HR	MIN	HR	MIN

FORMAT E

AGE UTILIZATION

DATE		EQUIP. MENT		AIRPORT		USING		SPOT TIME		START TIME		STOP TIME		REMOVE TIME		CARD CODE	
AV	NO.	TYPE	REB	TAIL	NUMBER	WIRE	CENTER	HR	MIN	HR	MIN	HR	MIN	HR	MIN	HR	MIN

FORMAT F

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[illegible][illegible][illegible]

EDIT PROGRAM OUTPUT

[illegible]

ON-AIRCRAFT MAINTENANCE

START TIME				STOP TIME				CITY SIZE	BASIC WORK CENTER	WORK ORDER PREFIX	TAIL NUMBER	WORK ORDER SUFFIX	MAN NUMBER	WORK UNIT CODE	ACTION TAKEN	WHEN DISCOVERED	HOW	MAINTENANCE UNITS	LABOR HOURS	ASSISTING WORK CENTER	REPORT NUMBER	SQUADRON	CARD CODE	
DAY	MO.	HR.	MIN.	DAY	MO.	HR.	MIN.																	
2	3	4	5	8	1	2	3	7	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

ON-AIRCRAFT WORK DELAY

[illegible]

EDIT PROGRAM OUTPUT

[illegible][illegible][illegible]

EDIT PROGRAM OUTPUT

AIRCRAFT STATUS

IN TO STATUS				OUT OF STATUS				STATUS CODE		TAIL NUMBER		NORS WORK UNIT CODE		SQUADRON		CARD CODE							
DAY	MO.	HR.	MIN.	DAY	MO.	HR.	MIN.																
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

FORMAT Q

MANPOWER AVAILABLE

DATE		MANPOWER AVAILABLE BY HOUR																											
WORK CENTER	DATE	MO.	DAY	HR.	MIN.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

FORMAT R

AGE UTILIZATION

SPOT TIME				START TIME				STOP TIME				REMOVE TIME		TAIL NUMBER		SUFFIX		NOUN		WORK CENTER		NOUN (CONK.)		AGE CODE		NOUN (CONK.)		CARD CODE	
DAY	MO.	HR.	MIN.	DAY	MO.	HR.	MIN.	DAY	MO.	HR.	MIN.	DAY	MO.	HR.	MIN.														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6

FORMAT S

EDIT PROGRAM OUTPUT

FORMAT 1

FORMAT U

FORMAT V

24-HOUR SPREAD SUMMARY CARD

[illegible]

ANALYSIS OF VARIANCE OUTPUT SUMMARY

[illegible]

REC'SUM PROGRAM SUMMARY

[illegible]

PROGRAM OUTPUT SUMMARY CARDS

FREQUENCY COUNT (FREQ) SUMMARY OUTPUT

FORMAT Z

[illegible]

OFF-EQUIPMENT (AFTO 211) MANHOURLY SUMMARY CARD

FORMAT AA

DATE		MANHOURS	TENTHS	HOURS	PRI/SEC	CARD CODE	A
MM	DD						
01	01						
01	02						
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01	27						
01	28						
01	29						
01	30						
01	31						

PROGRAM CONTROL CARDS

LAG DELAY CONTROL CARD

NO.	LAG	DELAY
1	2	2
2	2	2
3	2	2
4	2	2
5	2	2
6	2	2
7	2	2
8	2	2
9	2	2
10	2	2

FORMAT C1

CARD 11111

11 PUNCH

ANALYSIS OF VARIATE CONTROL CARD

NO.	LAG	DELAY	ANALYSIS	OF VARIATE	CONTROL	CARD
1	2	2	2	2	2	2
2	2	2	2	2	2	2
3	2	2	2	2	2	2
4	2	2	2	2	2	2
5	2	2	2	2	2	2
6	2	2	2	2	2	2
7	2	2	2	2	2	2
8	2	2	2	2	2	2
9	2	2	2	2	2	2
10	2	2	2	2	2	2

FORMAT C2

CARD 11111

11 PUNCH

AIRCRAFT HISTOGRAM CONTROL CARD

NO.	LAG	DELAY	AIRCRAFT	HISTOGRAM	CONTROL	CARD
1	2	2	2	2	2	2
2	2	2	2	2	2	2
3	2	2	2	2	2	2
4	2	2	2	2	2	2
5	2	2	2	2	2	2
6	2	2	2	2	2	2
7	2	2	2	2	2	2
8	2	2	2	2	2	2
9	2	2	2	2	2	2
10	2	2	2	2	2	2

FORMAT C3

CARD 11111

11 PUNCH

PROGRAM CONTROL CARDS

TABLE LOADING STOPPER

FORMAT C4

CARD CODE

11-4-8 PUNCH

MANPOWER UTILIZATION TITLE CARD

FORMAT C5

TITLE

11-4-8 PUNCH

EDIT PROGRAM GANGRUNCH MASTER CARD

FORMAT C6

11-4-8 PUNCH

PROGRAM CONTROL CARDS

DISPLAY PROGRAM DATE SELECT CONTROL CARD

DATE	DAY	MO	YR

FORMAT C7

11-00 PM H

DISPLAY PROGRAM TAPE OUTPUT CONTROL CARD

FORMAT C8

CARD COUNT

11-00 PM H

TAPE INPUT CONTROL CARD

FORMAT C9

INPUT TAPE

COUNT

PROGRAM CONTROL CARDS

GENERAL TITLE CARD

GENERAL TITLE CARD									
TITLE CARD (80-COLUMN DESCRIPTION)									
1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

FORMAT C10

HISTOGRAM TITLE CARD

HISTOGRAM TITLE CARD									
TITLE CARD (RIGHT OR LEFT HISTOGRAM)									
1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

FORMAT C11

FIELD SELECTOR CONTROL CARD

FIELD SELECTOR CONTROL CARD			
MINOR CONTR.	FIELD	FIELD TO ACCUMULATE	
HIGH ORDER	LOW ORDER	HIGH ORDER	LOW ORDER
1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32
33	34	35	36
37	38	39	40
41	42	43	44
45	46	47	48
49	50	51	52
53	54	55	56
57	58	59	60
61	62	63	64
65	66	67	68
69	70	71	72
73	74	75	76
77	78	79	80
81	82	83	84
85	86	87	88
89	90	91	92
93	94	95	96
97	98	99	100

FORMAT C12

PROGRAM CONTROL CARDS

COMPUTE ELAPSED TIME PROGRAM - CODE SELECTOR

INPUT TAPE COUNT	01 02 03
CODE TO SELECT	01 02 03

FORMAT C13

FREQUENCY COUNT (FREQ) FIELD LOCATOR CARD

LOCATION FIELD 1		LOCATION FIELD 2		LOCATION FIELD 3	
HIGH ORDER	LOW ORDER	HIGH ORDER	LOW ORDER	HIGH ORDER	LOW ORDER
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00	TITLE				

FORMAT C14

CHI-SQUARE TITLE CARD

TITLE (1-79)					
CARD CODE	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00				

FORMAT C15

PROGRAM CONTROL CARDS

CHI-SQUARE FIELD CONTROL CARD

LOCATION OF BASE-LINE COUNT		LOCATION OF OBSERVED FREQUENCY COUNT		LOCATION OF CATEG. ID. IDENTIFICATION		LOCATION OF MAJOR CONTROL		INPUT TAPE COUNT
HIGH ORDER	LOW ORDER	HIGH ORDER	LOW ORDER	HIGH ORDER	LOW ORDER	HIGH ORDER	LOW ORDER	
27	28	29	30	31	32	33	34	35

FORMAT C16

11 PUNCH

CORRELATION FIELD DESIGNATION CONTROL CARD

VARIABLE NUMBER	MATRIX COLUMN HEADINGS	FIELD POSITION		ANY CHARACTER
		HIGH ORDER	LOW ORDER	
1				

FORMAT C17

WHOLE NUMBER DECIMAL SHEET

CORRELATION GENERAL TITLE CARD

CARD CODE	TITLE
1	

FORMAT C18

3-3-8 PUNCH

PROGRAM CONTROL CARDS

CORRELATION FIELD DESIGNATION TABLE STOPPER CARD

CORRELATION FIELD DESIGNATION TABLE STOPPER CARD										
FORMAT C19										
11-4-8 PUNCH										

CORRELATION INDEPENDENT VARIABLE TEST CONTROL CARD

DEPENDENT VARIABLE TESTED										
FORMAT C20										
3-8 PUNCH										

ANALYSIS OF VARIANCE LEADER CARD

TITLE										
FORMAT C21										
CARD CODE										

MASTER TABLES

WORK CENTER MASTER

2-DIGIT WORK CENTER CODE	5-DIGIT WORK CENTER CODE	WORK CENTER NAME	FORMAT M1
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99		12 PUNCH

TAIL NUMBER MASTER

AIRCRAFT TYPE/MODEL/NUMBER	AIRCRAFT SERIAL NUMBER	TAIL NUMBER	WORK ORDER	STATION	ORGANIZATION (SQUADRON)	FORMAT M2
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99		11 PUNCH

2-DIGIT SYSTEM TABLE

2-DIGIT SYSTEM CODE	SYSTEM CONTROL	SYSTEM ALPHA	ABBREVIATION	FORMAT M3
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	11-3-8 PUNCH

EDIT PROGRAM AGE TABLE

AGE CODE	MOON	FORMAT M4
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99	0-1 PUNCH

- 83 -

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FORMAT CBI

[illegible]

FORMAT CD2

[illegible]

FORMAT CD3

FORMAT CD3										
CD	TAIL NUMBER	DATE		FRAG. NUMBER	CALL SIGN	PILOT	IDENTIFICATION NUMBER	COMMENTS	SEQUENCE CODE	CARD CODES
		DAY	MO.							
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COMBAT DRAGON SUPPLY EDIT OUTPUT CARDS

DEMANDS, RECEIPTS, AND CANCELLATIONS: CD Form 401, 402, June 1967

STOCK NUMBER										SUPPLY DOCUMENT NUMBER										RECEIPT OR CANCEL																																																											
QUANTITY										SERIAL NUMBER										TIME OF DEMAND																																																											
QUANTITY										SERIAL NUMBER										TIME OF DEMAND																																																											
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

CANNIBALIZATION TAPE FORMAT

STOCK NUMBER										SUPPLY DOCUMENT NUMBER										RECEIPT OR CANCEL																																																											
QUANTITY										SERIAL NUMBER										TIME OF DEMAND																																																											
QUANTITY										SERIAL NUMBER										TIME OF DEMAND																																																											
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

NORS: CD Form 403, June 1967

STOCK NUMBER										SUPPLY DOCUMENT NUMBER										RECEIPT OR CANCEL																																																											
QUANTITY										SERIAL NUMBER										TIME OF DEMAND																																																											
QUANTITY										SERIAL NUMBER										TIME OF DEMAND																																																											
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

DEMANDS, RECEIPTS, AND CANCELLATIONS: CD Forms 401, 402, June 1967

STATE NUMBER				SUPPLY DOCUMENT NUMBER				QUANTITY		TAIL NUMBER		EQUIPMENT TYPE		MAINTENANCE DOCUMENT NUMBER		WORK UNIT CODE		MISSION NUMBER		FILE OR KILL		TIME OF DEMAND		RECEIPT OR CANCEL		C																																																					
PSC	AREA	ITEM	Additional:	SERIAL NUMBER	JULIAN DATE	SHIP	AT (C/N)	SERVICE	UNIT (C/N)	ISSUE	SERIAL NUMBER	JULIAN DATE	SHIP	AT (C/N)	SERVICE	UNIT (C/N)	ISSUE	SERIAL NUMBER	JULIAN DATE	SHIP	AT (C/N)	SERVICE	UNIT (C/N)	ISSUE	SERIAL NUMBER	JULIAN DATE	SHIP	AT (C/N)	SERVICE																																																		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

CANNIBALIZATION CARD FORMAT

S*CK NUMBER				QUANTITY		WORK UNIT CODE		SERIAL NUMBER PART FOR		SUPPLY DOCUMENT NUMBER				SERIAL NUMBER PART FROM		TIME OF MAINTENANCE CONTROL ACTION		MAINTENANCE REPORT NUMBER FOR TO AIRCRAFT		MAINTENANCE REPORT NUMBER FOR FROM AIRCRAFT		CANNIBALIZATION SERIAL NUMBER		EQUIPMENT TYPE																																																						
SEC	MIN	HR	DAY	ADDITIONAL																																																																										
1	2	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

NOBS: CD Form 403, June 1967

STOCK NUMBER										QUANTITY										SUPPLY DOCUMENT NUMBER										TAIL NUMBER										EQUIPMENT TYPE										WORK UNIT CODE										ON MOVS										OFF MOVS																													
1-5					6-10					11-15					16-20					21-25					26-30					31-35					36-40					41-45					46-50					51-55					56-60					61-65					66-70					71-75					76-80																								
1					2					3					4					5					6					7					8					9					10					11					12					13					14					15					16					17					18					19					20				
1					2					3					4					5					6					7					8					9					10					11					12					13					14					15					16					17					18					19					20				
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DOCUMENT CONTROL DATA

1 ORIGINATING ACTIVITY THE RAND CORPORATION		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
		2b. GROUP
3. REPORT TITLE THE RAND/TAC INFORMATION AND ANALYSIS SYSTEM: VOLUME III--THE ANALYSIS DESIGN AND METHODS		
4. AUTHOR(S) (Last name, first name, initial) Finnegan, Fred and Anders Sweetland		
5. REPORT DATE January 1969	6a. TOTAL No. OF PAGES 103	6b. No. OF REFS. ---
7. CONTRACT OR GRANT No. F44620-67-C-0045	8. ORIGINATOR'S REPORT No. RM-5668-PR	
9a. AVAILABILITY/LIMITATION NOTICES DDC-1		9b. SPONSORING AGENCY United States Air Force Project RAND
10. ABSTRACT A description of the Rand/Tactical Air Command system for the collection, processing, and analysis of data, as implemented on an IBM 1401 computer, in the management and evaluation of aircraft operations and support at base level. The third volume in the series documenting the system focuses on analysis fundamentals: dependent and independent variables, data fields, sorting, data selection, and tagging. Areas of interest to maintenance analysts, such as aircraft turnaround and recovery, write-ups and break-rates, and job durations, are illustrated, the user being encouraged to explore the data imaginatively. Companion volumes in the series are Vol. I: <u>Data Collecting and Editing</u> (RM-5666-PR); Vol. II: <u>The Analysis Programs and Procedures</u> (RM-5667-PR); and Vol. IV: <u>The System Software</u> (RM-5669-PR).		11. KEY WORDS Aircraft Tactical Air Command (TAC) Operations Analysis Maintenance Materials Information systems Information processing Evaluation methods Rand/TAC Information and Analysis System